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Assessing the effect of shipboard motion and sleep surface on sleep effectiveness

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THESIS

ASSESSING THE EFFECT OF SHIPBOARD MOTION AND SLEEP SURFACE ON SLEEP EFFECTIVENESS

by

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Matthew C. Sullivan

December 2009

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13. ABSTRACT (maximum 200 words)

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ASSESSING THE EFFECT OF SHIPBOARD MOTION AND SLEEP SURFACE ON SLEEP EFFECTIVENESS

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
CIC	Combat Information Center
EEG	Electroencephalography
HSC	High Speed Craft
IRB	Institutional Review Board
JHSV	Joint High Speed Vessel
LCS	Littoral Combat Ship
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NPS	Naval Postgraduate School
NSWW	Navy Standard Work Week
OPTEMPO	Operational Tempo
REM	Rapid Eye Movement
RMS	Root Mean Square
SAFTE	Sleep Activity Fatigue and Task Effectiveness
TTP	Tactics Techniques and Procedures
V/E	Visco-Elastic
VMS	Voyage Management System
WAM	Wrist Activity Monitor

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I. INTRODUCTION

A. PROBLEM STATEMENT

In the Surface Navy, sleep is often considered a luxury. As any surface Sailor or officer knows, between standing watch and performing primary and collateral duties, there is little time left for proper rest. A Sailor or officer who is not well rested may be dangerously limited in his or her ability to carry out his or her responsibilities. Even when sleep time is available, it can be interrupted at a moment's notice for drills, or actual casualties. The problem is that a poorly rested crew presents a hazard to a ship and its mission.

If one were to imagine a ship in a high traffic area, such as the approach to the Panama Canal, the aforementioned issues become clear. Merchant traffic, as well as local fishing activity, is high, at times even chaotic. The ship may be underway in the middle of the night with poor visibility. The radar picture is obscured, and bridge-to-bridge radio is flooded with traffic. Therefore, the onus is on the watch team, primarily the team on the bridge, to maintain alertness. This team could be composed of deck seamen and two or three junior officers. Disaster could be around every turn; making sure that each member of the watch team is sufficiently rested is paramount.

The purpose of this study is to assess the effects of shipboard motion on sleep and sleep efficiency. While at sea, the schedule of every naval officer and enlisted Sailor permits less time for sleep than many have ever experienced. Their schedules may include both systemic and acute sleep disruption. Therefore, the quality of sleep, when available, becomes crucial for both human and ship performance. It is common knowledge to the nautically experienced that heave, pitch, and roll affect sleep quality. An extreme example of disrupted sleep is the inability to sleep due to intense weather or operational requirements. While this research is directly applicable to traditional, mono-hulled vessels, this study proposes considering the sleep quality associated with new ship classes, e.g., the Littoral Combat Ship, the High Speed Vessel, and other catamaran-style vessels. These hull designs may introduce particularly important factors concerning sleep

quality. With this in mind, this study's research questions are: how does shipborne sleep quality change with ship motion, and what actions can be taken to mitigate and/or eliminate factors that degrade sleep quality on U.S. Navy ships? A working premise is that to the extent that Naval crews obtain better sleep quality and are more rested, both individual human and total ship system performance are improved. Examples of potentially beneficial interventions to improve sleep aboard ships include the structural arrangement of berthing racks, adequate time allotted for sleep, properly constructed watch bills, and adequate crew size.

At the same time that the U.S. Navy is adding advanced technology, it is reducing overall end strength in line with the current manpower downsizing trend. More time allocated for sleep might translate into a need for larger crews, which is not the strategic direction of current Naval doctrine, according to Ewing (2009). Current doctrine espouses reduced platform manning as a result of technological advancements, e.g., propulsion systems and computers, which are assumed to require less manual labor. Thus, it is imperative that the U.S. Navy factor sleep efficiency into the equation when determining future crew size requirements.

A great deal of research has already been done in the area of fatigue and human performance. By examining that research, as well as the results of laboratory experimentation conducted as a part of this thesis, the authors present a plan for the improvement of sleep aboard Navy ships. This thesis effort encompasses factors such as sleeping surface, crew size, watch size and rotation. In addition, it takes into account the varying sea and weather conditions in which a ship may find itself.

B. OBJECTIVES

This thesis studies the effects of motion on sleep efficiency on catamaran-style Naval platforms, such as the High Speed Vessel. In addition, a standard Navy mattress is compared to a visco-elastic (V/E) foam mattress in order to ascertain if the change in sleeping surface improves sleep efficiency. Additionally, limited testing is conducted to determine the amount of shock and vibration that is transmitted through the two different mattress types.

C. RESEARCH QUESTIONS

- Does motion affect sleep efficiency?
- Is there a difference in sleep efficiency between the standard Navy mattress and a visco-elastic foam mattress?
- Is there a difference in the amount of shock and vibration transmitted through the two mattress types?

D. HYPOTHESES

Research Question One: "Does motion affect sleep efficiency?" This study hypothesizes that there is a significant difference in sleep efficiency between stationary and motion sleeping conditions. Sleep efficiency is defined as the proportion of sleep in the period potentially filled by sleep, or the ratio of total sleep time to time in bed, according to Sleepnet.com (2009). The experience of the pilot study (Grow and Sullivan, 2009) leads the authors to believe that sleep quality is degraded with motion. Specifically, this study predicts that the motion condition has a negative effect on sleep efficiency. While the pilot study did not yield statistically significant results (the study included only two individuals), the data suggested that motion does affect sleep. However, the visco-elastic foam and standard Navy mattresses were not used during the pilot study, as the goal was to assess the feasibility of the motion platform. The full results of the pilot study are recounted in Chapters III and IV.

Research Question Two: "Is there a significant difference in sleep efficiency between the two mattress types?" Some studies suggest that a visco-elastic foam mattress will lead to greater sleep efficiency. The authors hypothesize that the visco-elastic foam mattress will reduce the degradation in sleep efficiency caused by motion i.e., sleep with visco-elastic mattress will improve sleep.

Research Question Three: "Is there a significant difference in the amount of shock and vibration transmitted through the two mattress types?" The rationale for this question is that due to the composition of the mattresses, which will be discussed in greater detail

in Chapter III, the authors expect that the visco-elastic foam mattress will reduce the amount of the shock and vibration transmitted from the motion machine to the participant on the mattress.

E. HUMAN SYSTEMS INTEGRATION (HSI)

Human Systems Integration (HSI) is the central theme of this thesis. A relatively new field, HSI seeks to reduce costs and maximize performance through tradeoffs that focus on eight different domains. These domains are: health hazards, safety, human factors engineering, survivability, training, habitability, manpower, and personnel. This work is relevant to several of the Human Systems Integration domains. Manpower, human factors, safety, occupational health and habitability are all inextricably linked to sleep, sleep effectiveness, and reduced individual performance related to fatigue.

Manpower is relevant as the Navy considers new ship designs, such as the High Speed Vessel. These new ships, which are designed as catamarans, will have reduced manning and an increased emphasis on technology and automation. With this in mind, it is essential to ensure that the smaller crew has appropriate and the most effective sleep possible.

Habitability and human factors are vital domains because these new ship types will experience sea conditions in new ways. Catamaran-style ships tend to have a significantly rougher ride than do the traditional, mono-hulled ships, according to Ross (2009). Ensuring that the sleeping surface on each crewmember’s rack accounts for this change is important.

Safety enters into play because smaller crews will require each sailor to perform more tasks. If sailors are not properly rested, they may be unable to perform as expected when dangerous situations arise. By ensuring the maximum sleep efficiency, fatigue will be reduced, and crew focus, work productivity, and safety will be increased.

Occupational health is also a domain worth considering because of the dangers posed to the human body by excessive shock and vibration. Catamaran-style ships tend to have a significant amount of slamming, which, over time, could cause serious health problems. While there may be ways to reduce these negative effects on the ship as a

whole, this thesis focuses on reducing shock and vibration during sleep through the exploration of the use of different types of sleeping surfaces, namely the Tempur-Pedic™ mattress.

F. THESIS ORGANIZATION

Chapter II of this thesis focuses on the scientific literature available for sleep and fatigue in general; the effects of fatigue on performance, health and safety; shift work as it applies to watch standing and crew rotation; and motion and vibration effects on sleep and health; and sleep quality and sleeping surfaces. Chapter III explains the nature of the equipment used in this study, the makeup of the sample, and a thorough description of the methodology used to obtain the results. Chapters IV and V present the analysis of our results and a discussion of what these results mean for the Navy, what future research should be conducted and how the Navy might make improvements in the years to come.

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II. LITERATURE REVIEW

A. OVERVIEW

Anyone who has ever served on a ship in the Surface Navy can tell you that sleep is a rare commodity. Between standing watch, doing a job, and performing collateral duties, sufficient sleep becomes an unaffordable luxury. However, as operational requirements increase and new ship types are introduced into the fleet, the importance of sleep becomes far greater than it has ever been. One goal of the Surface Navy must be to maximize the efficiency of sleep that is available to its Sailors. The next few sections of Chapter II are broken into several key areas. Section B provides an overview of the relevant literature concerning the general importance of sleep, followed by an examination of its specific importance in the Surface Navy. Section C discusses how changes in ship design drive the Navy to make decisions regarding crew size, watch rotation and sleep schedules. Section D discusses the current Navy Standard Work Week (NSWW). Section E discusses shiftwork as it relates to sleep quality and quantity. Section F examines the effects that shipboard motion has been to found to have on sleep, both on traditional, mono-hulled ships, and also on the newer, catamaran-style ships. Section G goes into greater detail concerning the effects of vibration. Section H examines the measures of sleep efficiency in use today. Section I gives a general recap of the pilot study that preceded this thesis. Finally, Section J focuses on the literature regarding sleeping surfaces and how the type of mattress used on Navy ships may impact the sleep of Sailors.

B. FATIGUE AND THE IMPORTANCE OF SLEEP

Although there is debate on what exactly happens to the human body and the human brain during sleep, sleep is vitally important to health and proper functioning. Without quality sleep in adequate amounts, the body becomes fatigued. According to Grandjean (1968), physiologists and psychologists vary in their understanding regarding the nature of fatigue. Grandjean notes that while physiology limits its definition of fatigue to a reduction in physical performance, the field of psychology believes that fatigue

effects manifest in motivational and cognitive aspects as well. It is also Grandjean's contention, based on modern neuroscience as of 1968, that the human brain controls alertness, or, alternatively, sleepiness through the reticular activation system. Furthermore, the cortex can be stimulated through this activating system when there is sufficient external stimulation, such as an interesting intellectual puzzle, or a threat to one's life. However, this activating system can only go so far. Eventually, fatigue can and will take its toll on performance.

According to Miller, Matsangas and Shattuck (2007), the amount and pattern of sleep changes over the course of a person's life. Figure 1, taken from Miller, et al. (2007), illustrates this point.

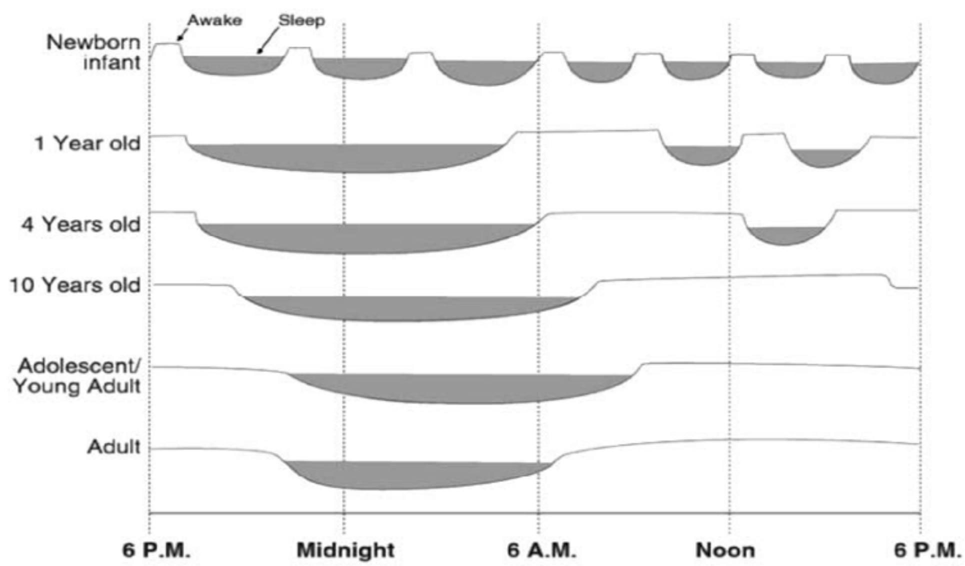

Figure 1. Sleep Requirements Throughout Life (from: Miller, Matsangas, and Shattuck, 2007)

Looking at this information, one can see how a large amount of contiguous sleep is required for ages ranging from adolescent to adult, which also covers most of the military population. An 18-year-old Sailor, or a 22-year-old division officer should be getting about 8.5 to 9.25 hours of sleep per night. Given current Navy schedules and practices, there is time for about half that amount. The obvious result of this problem is exhausted Sailors and officers. With chronic exposure to inadequate sleep the problem

worsens over time due to the resulting sleep debt, creating potentially dangerous situations during even the most routine shipboard operations.

The National Sleep Foundation (2009) notes that between 50 and 70 million people suffer from significant sleep problems. They also explain that these problems can lead to issues with attention and mood, as well as severe health conditions. It is clear that sleep has both psychological and physiological ramifications. The National Sleep Foundation (2009) explains that most Americans with sleep problems do not recognize that it is a serious problem and may do little or nothing to treat it. According to the Institute of Medicine (2009), among those millions who do seek treatment, the costs run to the hundreds of billions of dollars. One must consider the additional cost involved if a ship with overly fatigued Sailors runs aground or collides with another ship.

In a study by Belenky, Wesensten, Thorne, Thomas, Sing, and Redmond (2003), it was found that the human brain is able to compensate, to some extent, for sleep deprivation; however, the study also found that this ability is limited in both its scope and duration. The study had 36 volunteers spend varying amounts of time in bed per day, ranging from three hours to nine hours, followed by three days with a full eight hours of sleep. The results showed significant performance decrement on a psychomotor vigilance test. This test is comprised of a handheld device that measures user reaction times, shown in the vertical scale of Figure 2, to a series of visual stimuli. Furthermore, even after the three recovery days of eight-hour sleep periods, the degradation in task performance persisted. Figure 2, taken from Belenky et al. (2003), illustrates the design of this study, while Figure 3 illustrates the performance of the different groups on the psychomotor vigilance test. In Figure 2, TIB refers to time in bed. In both figures, the days labeled E refer to days with sleep exposure. Days labeled T refer to pre-experiment calibration days. Days labeled R refer to recovery days.

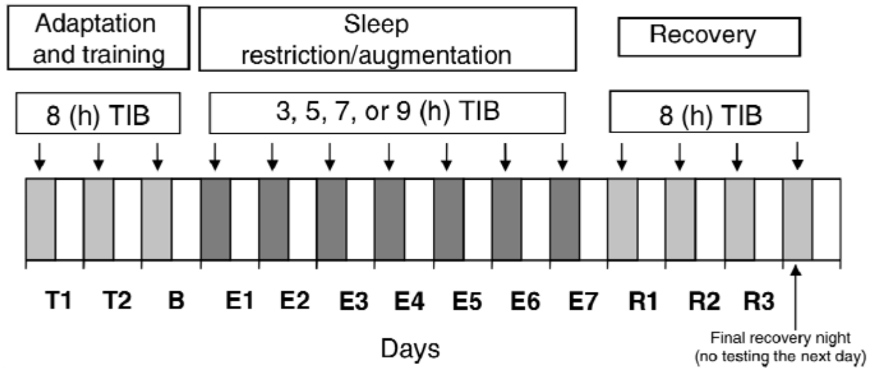

Figure 2. Daily Time in Bed (from: Belenky et al., 2003)

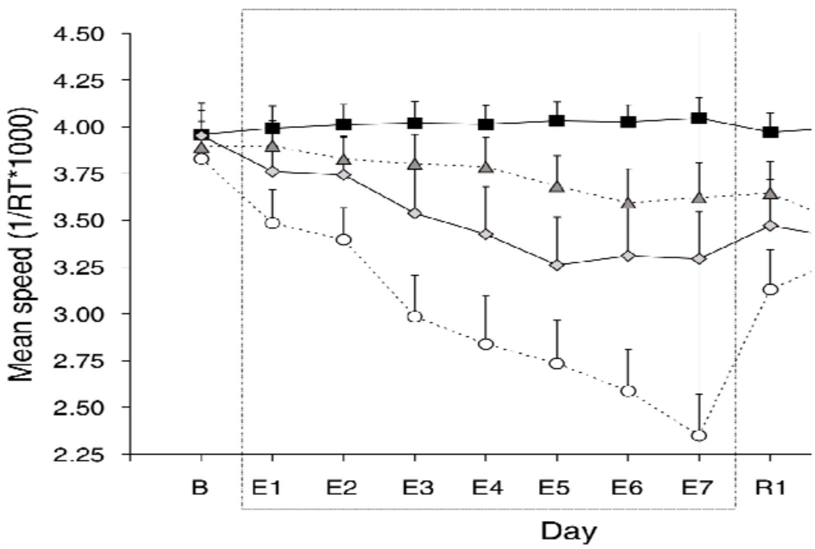

Figure 3. Psychomotor Vigilance Test Performance (from: Belenky et al., 2003)

The military is not exempt from the effects of sleep deprivation. According to Andrews (2004), the performance of military recruits was found to suffer significantly when they had insufficient sleep. Andrews (2004) also notes that in 2002, Navy policy changed so that recruits were given eight hours of sleep per night, whereas before, they received only six hours of sleep. The results were compelling, showing a significant increase in test scores and overall performance for those who received eight hours of

sleep. Figure 4, taken from Miller, Shattuck, Matsangas and Dyche (2008), illustrates the effect of sleep on test scores, with scores from 2000 and 2001 significantly lower than those of 2003.

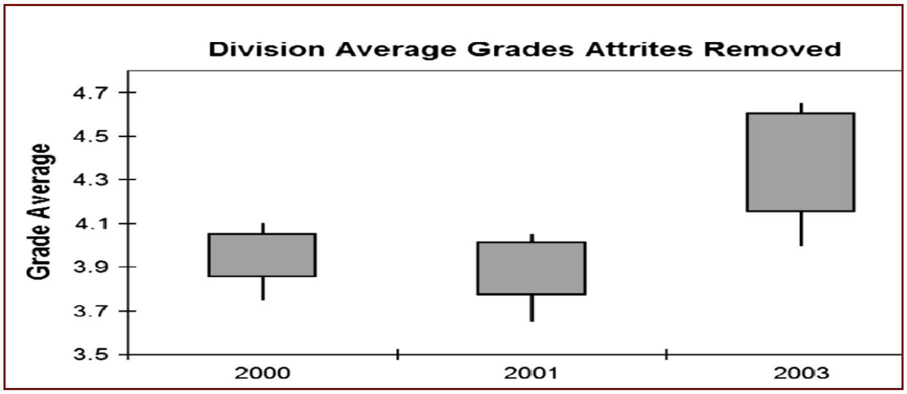

Figure 4. Allotted Sleep and Test Performance (from: Miller, Shattuck, Matsangas, Dyche, 2008)

Furthermore, Dawson and Reid (1997) note that when humans consistently obtain insufficient sleep, a sleep debt will build up. They also mention that this debt can lead to severely reduced performance, which can lead to potentially fatal accidents. When one considers the job of military personnel, even the recruits, the dangers of lack of sleep become clear.

These problems are not unique to the Navy. In 2009, Miller, Shattuck and Matsangas surveyed 49 Army officers at the Infantry Officers Advanced Course. All of these officers had recently returned from combat duty; thus, the study was aimed at discovering the effects of sleep hygiene to ascertain what their respective units employed in terms of tactics, techniques, and procedures (TTPs) to reduce the potentially devastating effects of sleep loss. The study produced a number of disturbing results. For example, in excess of 80 percent of the officers were not provided with any sort of sleep management plan, while over half reported that sleep deprivation, and the resulting fatigue, was a serious issue in their unit. At the same time, many of the officers reported that almost half of their time deployed was spent in a high operational status (optempo). During these periods, soldiers averaged roughly four hours of sleep per day. Given this information, and the fact that so much of the time that Sailors, Soldiers, and Marines are

deployed they are in a high optempo status, it is vital that the sleep that is available be as effective as possible. As far as the Navy is concerned, with new ship classes carrying smaller crews, there will be reduced opportunities for sleep, further emphasizing the need for that sleep to be as restorative as possible.

Van Dongen, Rogers, and Dinges (2003) studied the effects of restricted sleep, a common occurrence aboard ship. Chronic sleep restriction is a reduction in sleep over a period of time. Van Dongen et al. (2003) suggest that over time, sleep debt will build up. Similar conditions might be expected on a surface ship. With such limited opportunities to sleep, a large sleep debt can quickly accumulate. In their conclusion, Van Dongen et al. (2003) define sleep debt in terms of chronic sleep restriction. With the difficult and mentally taxing responsibilities of a Sailor in today's Navy, chronic sleep restriction and the ensuing sleep debt could be devastating.

Calhoun (2006) notes that fatigue among mariners is one of the leading causes of accidents on the high seas. He makes reference to the Exxon Valdez and Herald of Free Enterprise disasters as prominent examples of mishaps caused by fatigue. His paper focuses on how elements of ship design should be reconsidered to maximize sleep effectiveness and reduce crew fatigue. Table 1, taken from Calhoun (2006), goes into detail on the characteristics of positive sleep: duration, continuity, quality, and time of day.

Component	**Description**	**Notes**
1. Duration	Individual requirements are unique; minimum 7 - 8 hours in a 24-hour period.	Sleep loss effects are cumulative. See **Figures 4 and 5.**
2. Continuity	Sleep period must be uninterrupted.	Five stages of sleep; cycle throughout the sleep period. **See Table 2.**
3. Quality	Deep sleep/REM required for recuperation	Five stages of sleep. Each provides differing benefits.
4. Time of Day	Sleep during the day not as high quality as sleep during the night.	Circadian Rhythm is the driving factor. **See Figure 6**.

Table 1. Components of Sleep (from: Calhoun, 2006)

Examining this table, one finds that these components are rarely present in the sleep schedules of Sailors. Crews onboard U.S. Navy warships may have to sleep during the daytime one day, while sleeping at night the next. Rarely are they able to achieve eight hours of uninterrupted sleep.

C. THE LITTORAL COMBAT SHIP/JOINT HIGH SPEED VESSEL

Before going into details about the implications of these two ship types, it is necessary to describe what exactly catamaran means. According to Ross (2009), "catamarans are comprised of two parallel, slender and symmetric hulls connected by a cross structure and supporting superstructure." Ross goes on to explain that this design leads to a combination of pitch and roll, or a "corkscrew motion." Furthermore, Ross (2009) notes that this leads to a slamming effect.

The Littoral Combat Ship (LCS) merits some in-depth attention with regard to its design, as well as the proposed manning requirements that have been set forth by the Navy. While the LCS is not designed as a catamaran, one of the potential designs is a trimaran. Therefore, many of the same problems may apply. According to Douangaphaivong (2004) and others, most Sailors require between seven to nine hours of sleep to be completely effective mariners. Most Sailors do not have the opportunity for this much high-quality sleep on the mono-hulled ships in use today. Douangaphaivong (2004) goes on to discuss how the LCS will have significantly less manning than current ships. He notes that the minimum requirements for the LCS will be between 15 and 50 sailors, with a maximum range of 75 to 110. These numbers are far smaller than the crews of even today's smallest frigates. He adds that this small crew size and reliance on technology will save the Navy as much as $110 million, but one must consider the opportunity costs involved.

As a corollary to the points highlighted by Douangaphaivong, Work (2004) explains that the Navy intends to have an LCS that will have a small base crew, with facilities to bring mission-specific crews on board. However, Work (2004) notes that the maximum crew size, under any mission conditions, will not exceed 75 Sailors and

officers. Work's projected crew size is smaller than that of Douangaphaivong, but the salient point is that crew size on the LCS will be small. This fact, taken in concert with the fact that the LCS is intended to operate with a variety of unmanned aerial and submersible craft, means that the ship's mission will emphasize technology rather than personnel.

The trend towards smaller crews is not just limited to the LCS and other future ship designs. According to Colwell (2005), the crew sizes of North Atlantic Treaty Organization (NATO) vessels have been decreasing for many years now. Figure 5, taken from Colwell (2005) shows the decreasing crew size on seven NATO frigates and destroyers from 1955 to 1995. The vertical axis represents the number of persons for every 100 tons of vessel displacement.

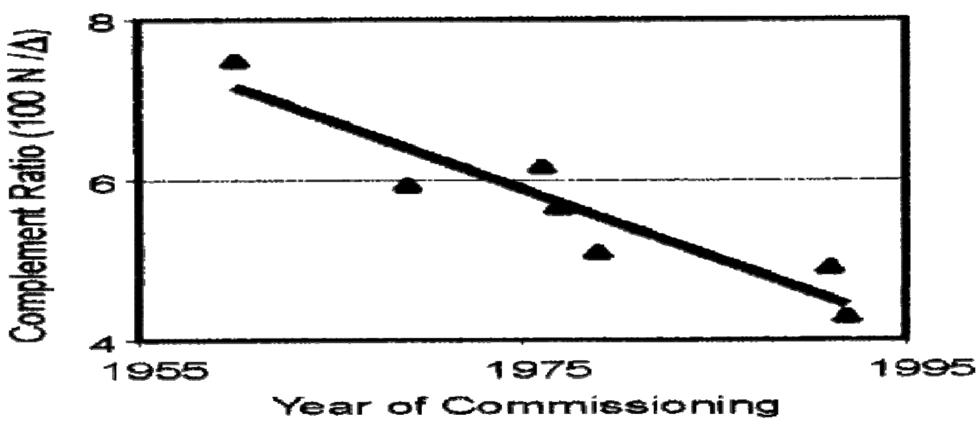

Figure 5. Crew Sizes of NATO Ships (from: Colwell, 2005)

In addition, Colwell (2005) cites the results from a questionnaire that was given to 1,000 NATO Sailors. The questionnaire was designed to ascertain what Sailors considered to be the most relevant problems that they experienced with regard to ship motion. Table 2, taken from Colwell (2005), provides the results of this questionnaire. WS in the right hand column stands for weight severity and is an index that calculates a percentage based on the number of respondents who listed that problem and the degree of severity that they assigned to it.

NATO questionnaire problem severity.

	PROBLEM DESCRIPTION	SEVERITY (%)
1	sleep quality and duration	30.4 (WS)
	mental and physical fatigue	20.3 (WS)
	motion sickness (nausea)	4.4 (WS)
	motion sickness (vomit)	1.5 (WS)
2	balance	14.4 (WS)
	carrying/moving things	11.4 (WS)
	hand coordination	11.4 (WS)
3	concentration	13.8 (WS)
	memory	7.8 (WS)
	decision making	7.6 (WS)
4	tasks not completed	10.8
	longer time required	10.3
	more mistakes than usual	4.9
5	noise and vibration	23.9 (WS)
	air quality	20.2 (WS)
	lighting and temperature	16.0 (WS)

Table 2. Primary Problems Reported by NATO Sailors (from: Colwell, 2005)

In a recent article in the Navy Times, Ewing (2009) discusses how the reduction in crew sizes is impacting the ships of today's Navy. The primary example he cites is that of the USS Port Royal grounding. The incident report, following the grounding, noted that the commanding officer was extremely fatigued and the qualified lookouts were all occupied with other tasks, largely due to the reduced manning. According to Ewing (2009), these manning issues appear to be Navy-wide in their scope. He cites worsened materiel readiness, a lack of qualified personnel, and, perhaps most importantly, overly fatigued crews as the key consequences of the Navy's manning policies. While the reduction in manning on today's warships may seem like a bad policy, many of the Navy's past and present leaders sought to move down this path in order to prepare for future ships such as the LCS. Ewing (2009) quotes retired Vice Admiral Timothy Lefleur who said "in the ships of the future, like [the littoral combat ship] and DD(X), we're going to have optimally manned crews. When DD(X) and LCS arrive, we have to have that infrastructure in place." However sensible reduced manning may seem in this context, the negative results require attention. Otherwise, there will most likely be more incidents like the grounding of the Port Royal, according to Ewing (2009).

Part of Douangaphaivong's (2004) thesis dealt with the problem of fatigue, given the small crew size of the LCS. He explains how the goal for the effectiveness of key

watchstanders defined as those Sailors standing watch on the bridge and the combat information center (CIC), should be 80 percent, and 65 percent at a bare minimum. However, Figure 6, taken from Douangaphaivong (2004), shows how over the period of a 30-day underway, measured from the vertical red line. Crew effectiveness, shown on the Y axis, was rarely above 70 percent and even dipped below 50 percent at times.

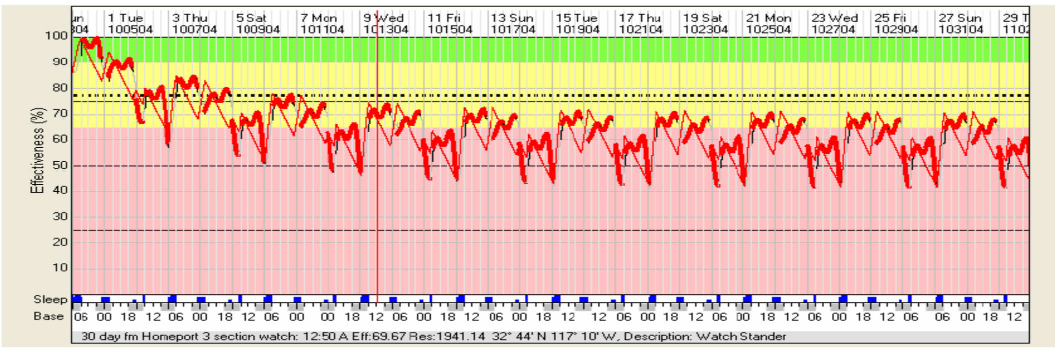

Figure 6. Predicted Crew Effectiveness Underway Based on FAST Data (from: Douangaphaivong, 2004)

Douangaphaivong (2004) notes that predicted effectiveness could be brought up to 75 percent, which is acceptable, with the sleep time allotted from 2200-0600, but he cautions that this sleep must be of the highest quality.

According to Thomas et al. (2003), catamaran-style vessels experience “…wet deck slam events that can impart a high localized pressure in the region of impact and a large global load onto the vessel’s structure.” Figure 7, taken from Thomas et al. (2003), illustrates these impacts.

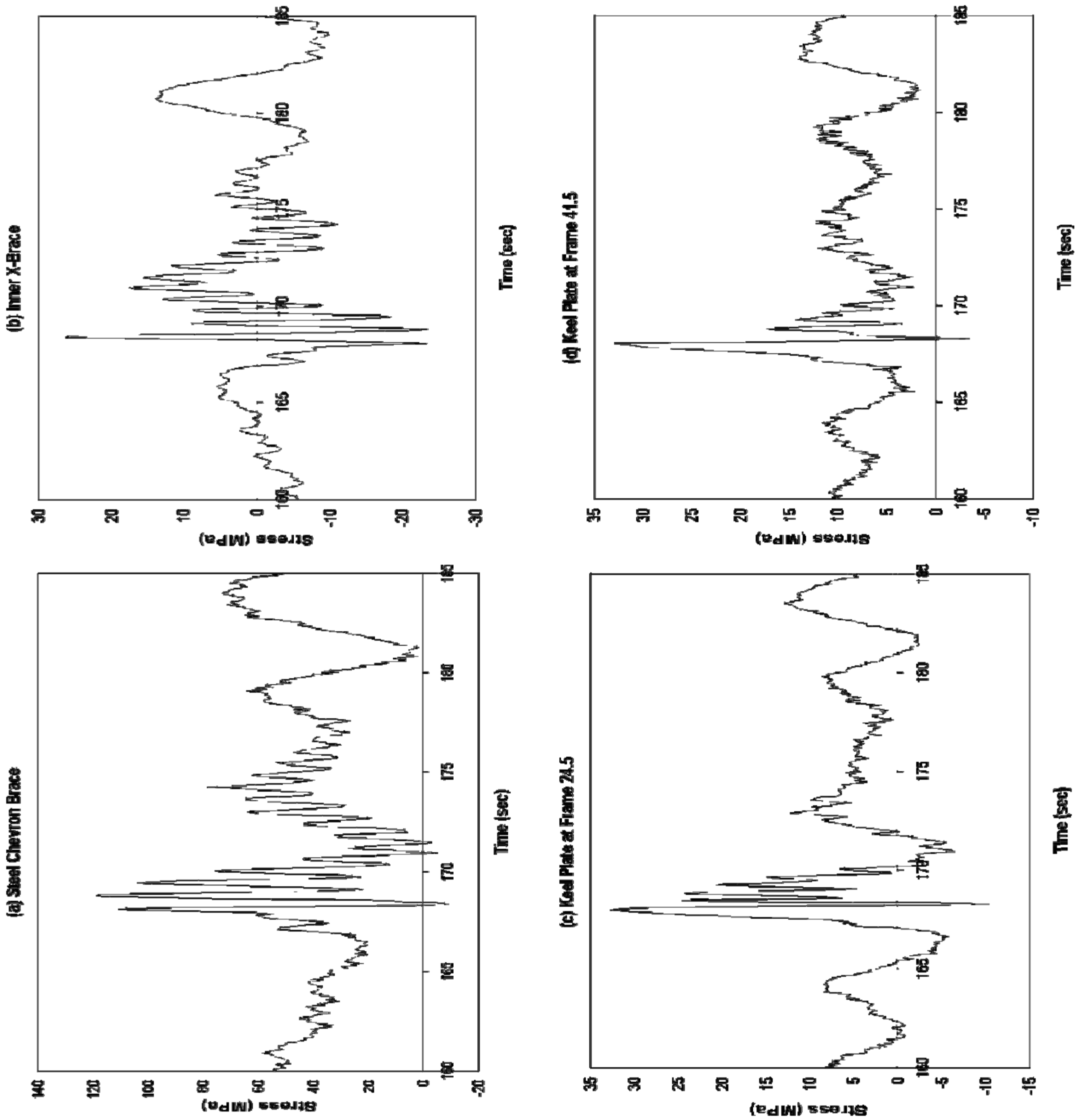

Figure 7. Hull Stress on Catamarans (from: Thomas et al., 2003)

This information was obtained during a study conducted by Thomas et al. (2003), which utilized a catamaran ferry, which ran from Sydney to Fremantle, Australia. Three accelerometers, as well as rate gyros, were placed throughout the vessel to acquire the data. The sharp spikes indicate significant slamming events. According to Waterhouse (2002), mono-hulled ships tend to experience less severe pitching, and thus, less slamming. What this means is that at high speeds the slamming of a catamaran vessel

would negatively affect ship and crew performance far more than on a mono-hulled vessel. Figure 8, taken from Thomas et al., (2003) illustrates how and where these devices were used.

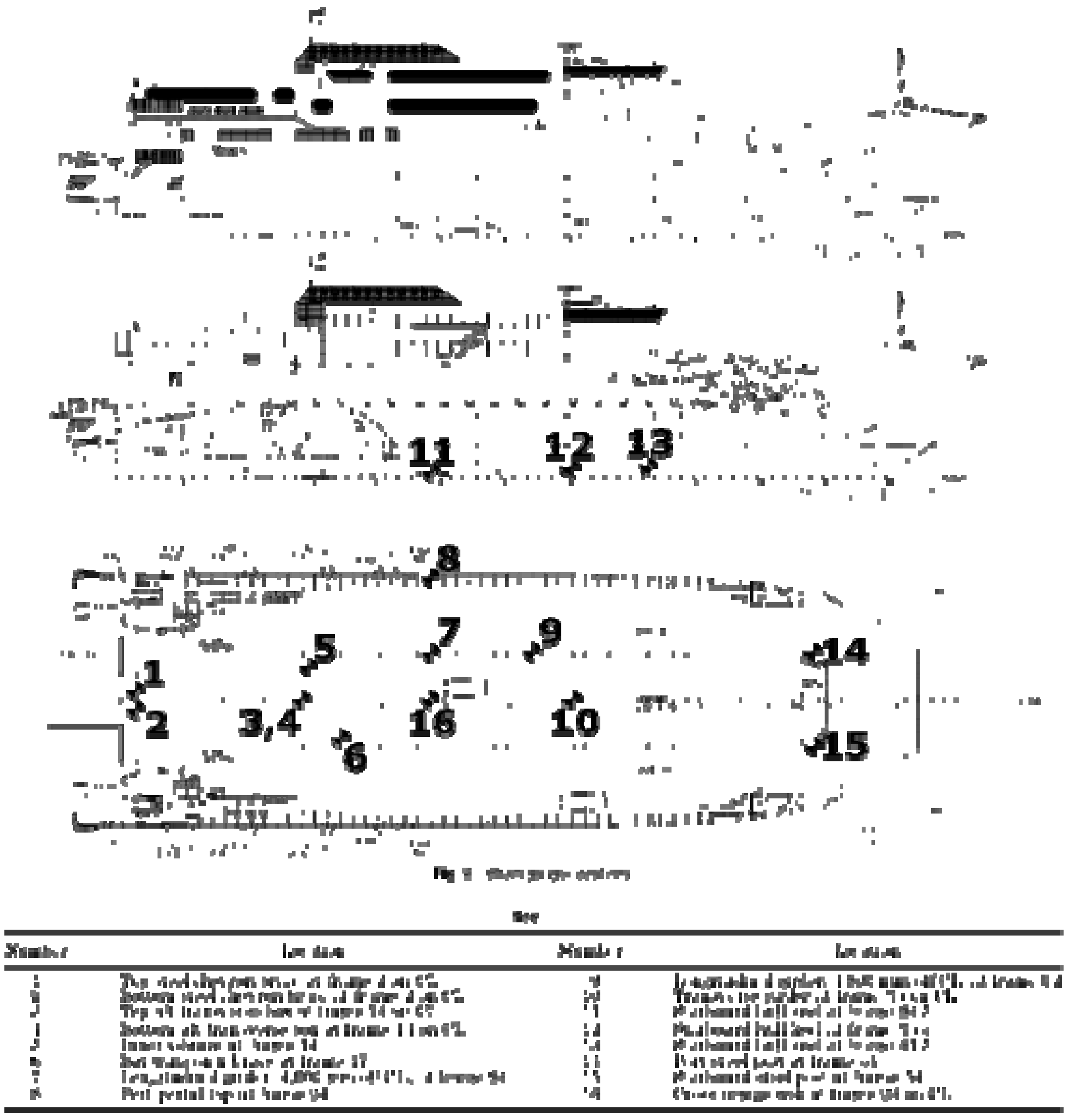

Figure 8. Accelerometer and Gyro Locations (from: Thomas et al., 2003)

Given the slamming motions and vibrations that are experienced by Sailors on catamaran-style ships, high quality sleep seems unlikely. These facts only underscore the need to assess exactly how much the sleep of these Sailors will be affected by motion and vibration on these new ships, and how crew size and watch schedule must be designed

around these facts. Finally, every effort must be made to improve the sleeping surfaces of the Sailors to complement a revised watch schedule.

As further support for this point, Rudko (2003) notes that catamaran-style vessels, which are capable of very high speeds, do not handle well in high seas and inclement weather. Figure 9, taken from Rudko (2003) illustrates how sea conditions can affect different hull types. What this figure illustrates is maximum speed that a given vessel type is able to travel at varying wave heights. The swath/slice hull type was not included in Rudko's analysis.

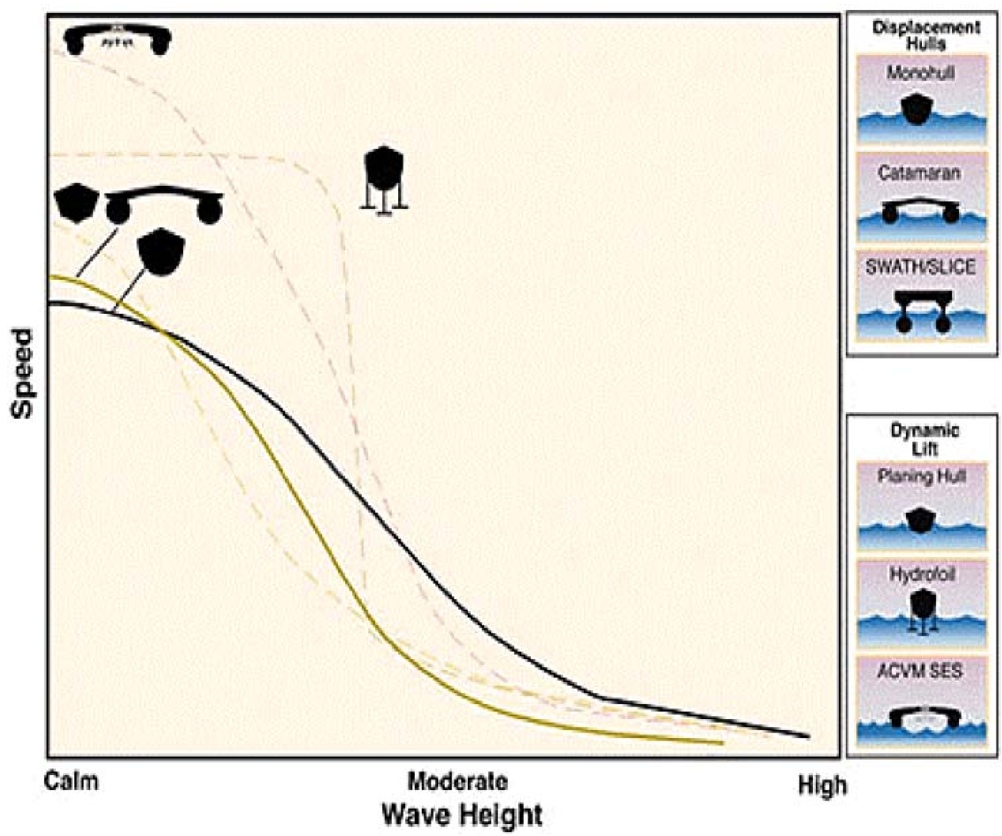

Figure 9. Hull Types and Sea Keeping (from: Rudko, 2003)

Rudko (2003) also cites the example of a previous catamaran-style vessel, the USS Ashville. The problem with the USS Ashville was that it experienced extremely heavy heave, pitch and roll in rough seas. In seas as small as eight feet, it could experience rolls as great as 65 degrees. Rudko notes that this type of motion caused

significant problems for the crew’s sleep. Over a short period of time in these conditions, fatigue began to take its toll on the crew. These points illustrate the need to modify sleeping conditions to include sleeping surfaces, in order to alleviate this problem in the catamaran-style vessels of the future.

Another ship class worth considering is the Joint High Speed Vessel (JHSV). This future class of ship, which is very similar to the USS Swift (HSV-2) in its design, will cause many of the same types of sleep disturbances that have already been mentioned. The JHSV, according to the PEO Ships Web site (2009), is intended for use by both the Navy and the Army. It is to be designed as a high-speed transport ship able to travel at sustained speeds of 35-45 knots. Figure 10, taken from the Defense Industry Daily web site (2009), illustrates the most likely hull design for the JHSV.

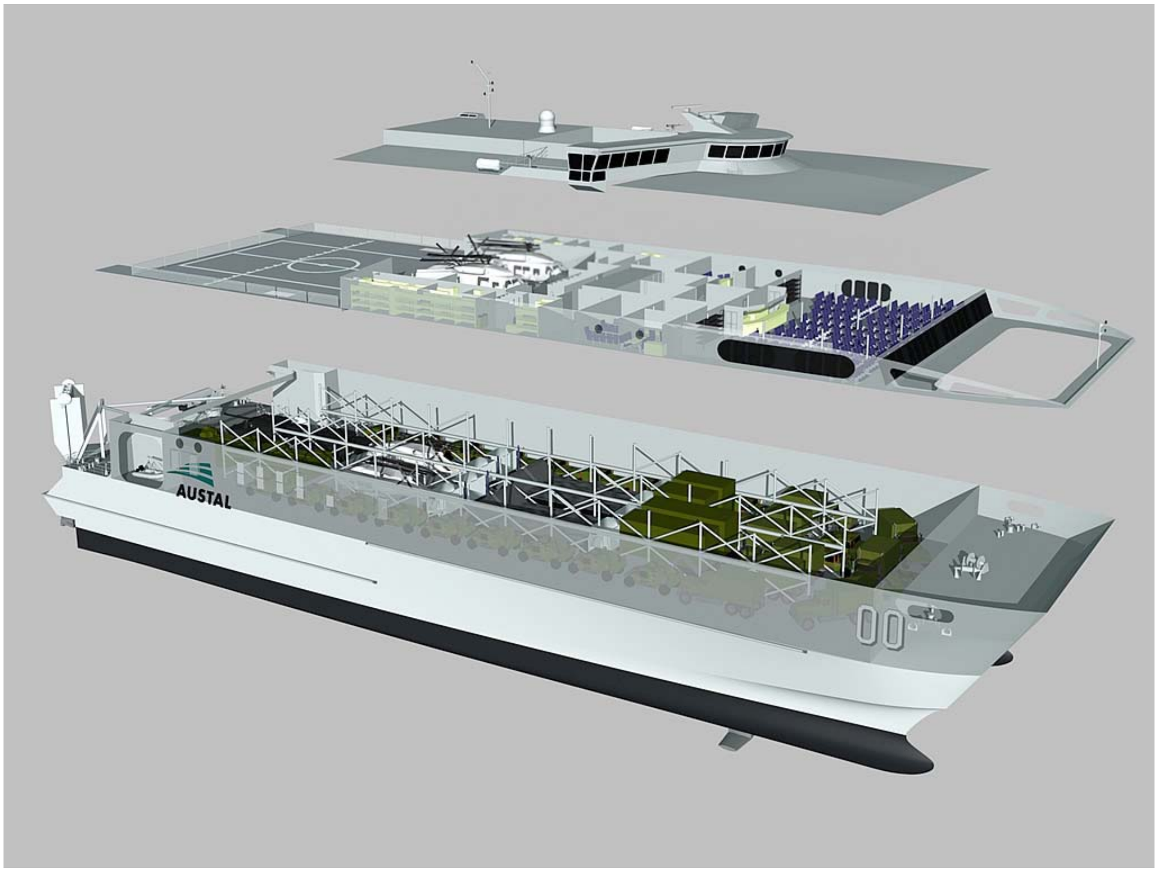

Figure 10. Hull Design of the JHSV (from: Defense Industry Daily 2009)

According to Fagan (2007), the JHSV will cut back manning to a mere 78 sailors. This was accomplished through the removal of a number of jobs that are standard on most Navy ships today, including the ship's store, disbursing office, and separate chief/officer wardrooms. By reducing manning, as with the LCS, each Sailor will be asked to do more with fewer opportunities for sleep. Because of this fact, it is vital that the sleep allowed is as efficient and restful as possible.

D. NAVY STANDARD WORK WEEK

Having considered the conditions of the LCS, as well as catamaran-style ships, it is necessary to review the implications of these new ship designs as they relate to the NSWW. According to Haynes (2007), the Navy currently allows for 81 hours for work-related activities in a given week and 70 hours of productive work. Of the remaining time, 56 hours per week are set aside for sleep, which equates to eight hours per day. While eight hours may seem like adequate time for sleep, one must consider that these times are based on Condition III, or peacetime steaming. In addition, it is unlikely that Sailors will be able to keep to this sleep schedule, as operational requirements, not to mention the everyday routine, will cut into the allotted sleep time. Figure 11, taken from Haynes (2007), demonstrates how the Navy's standard workweek is often violated. The gold bars represent the time per day allocated by the NSWW, while the blue bars represent the actual daily schedule of one of the Sailors on the USS Chung Hoon while deployed.

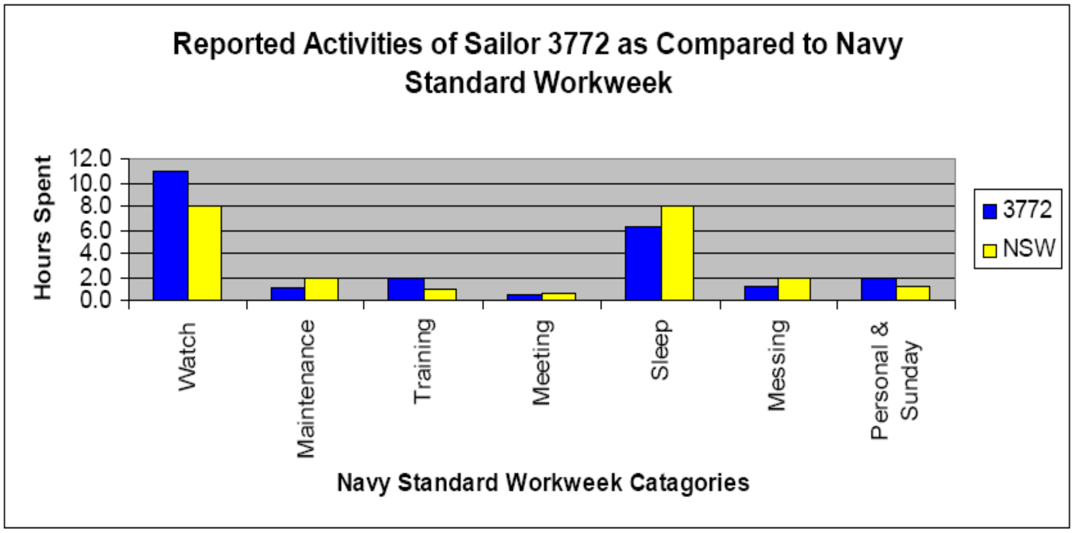

Figure 11. Workweek and Actual Activities (from: Haynes, 2007)

It is important to note that this figure represents only one Sailor on one ship, and may not be the same as all Sailors on all ships. The calculations on sleep are of particular importance. Where the Navy allots eight hours for sleep, the Sailor in question here received six hours. With the reduced manning and violent motions of future ship designs, it is reasonable to assume that the amount of time allotted for sleep will only decrease, further underscoring the need to maximize sleep efficiency during the time that is actually available. Furthermore, Haynes (2007), who utilized the Fatigue Avoidance Scheduling Tool (FAST), found that 56 percent of the Sailors who were surveyed showed a predicted effectiveness of below 80 percent. According to Haynes, this translates into fatigue with operational consequences for a majority of the crew.

Williams-Robinson (2007) conducted a study using 40 members of the crew proposed for the LCS-1, USS Freedom. Her study showed that even in a 70-hour workweek, crew endurance was exceeded by 594 hours over the course of a 14-day period. In addition to this, she notes that 42 percent of the crew had higher than acceptable levels of fatigue. Haynes and Williams-Robinson, taken together, illustrate how reduced manning and new ship designs will create serious fatigue issues that will

require a reevaluation of the NSWW, as well as the manning and watch rotation schedules of the LCS, JHSV, and other future ship designs.

What is also of great concern is the fact that there are a number of variations on the NSWW that must be considered. According to Miller and Firehammer (2007), there are three general steaming conditions on U.S. Navy ships. In Condition I, which is wartime steaming, the crew, in effect, must remain on duty for up to 24 hours. In Condition II, no less than four to six hours of sleep should be allotted per day for a period of 10 days. Finally, in Condition III, which is peacetime steaming, eight hours of sleep should be allotted per day for up to 60 days. However, these requirements are not always met. Table 3, taken from Miller and Firehammer (2007) represents the breakdown of the NSWW. Table 4, taken from Miller and Firehammer (2007), shows that on most ship classes in service today, the number of hours spent working, that is watch and ship's work, exceeds the amount alloted by the NSWW.

Activity	Hours per Week
On-duty time (all work)	81
Productive work	70
Training	7
Service diversion	4
Unavailable time	87
Sleeping	56
Messing	14
Personal needs	14
Sunday free time	3

Table 3. NSWW Breakdown (from: Miller and Firehammer, 2007)

Ship Class	Watch+Ship's Work	Evolutions	General Qtr	Wkly Total
LHD	65.8	2.2	2.8	70.8
LSD	72.6	4.8	0	77.4
CVN	69.9	1.4	2.7	73.7
DDG	73.4	4.7	0	78.1
C	65.4	14.8	0	80.2
Average	69.5	4.0	1.6	75.1

Table 4. Productive Work Hours on Various Ship Types (from: Miller and Firehammer, 2007)

E. SHIFTWORK

The problem of sleep deprivation increases in importance when one considers shiftwork. According to Knuttson (2003), there are serious health effects related to shiftwork and sleep. Among these effects are gastrointestinal disorders and coronary problems. Furthermore, Knuttson (2003) notes that many of the processes of the human body are dependent on the circadian rhythm. For example, people with epilepsy are more likely to experience seizures when sleep deprived. Figure 12, taken from Knuttson (1989) illustrates these points. As this figure shows, shift work can be the catalyst for a myriad of issues that can lead to health problems.

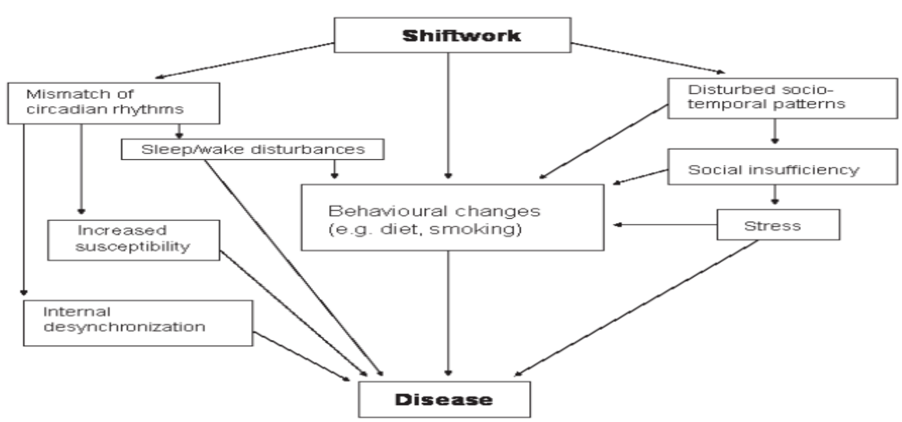

Figure 12. Problems with Shiftwork (from: Knuttson, 2003)

Sleep efficiency, motion, and sleeping surface are all related to crew size and watch schedule. Lutzhoft, Thorslund, Kircher, and Gillberg (2007) studied Swedish-based merchant ships where they looked at the fatigue levels of Sailors on a two-watch system versus sailors on a three-watch system. In their study, some Sailors were on a six hours on, six hours off routine, while others were on a four hours on, eight hours off routine. They did not find statistically significant differences in level of fatigue, but based on their data, they believe that ships with a two-section watch schedule will have higher levels of fatigue than the three-section watch. The results of Lutzhoft et al. (2007) are relevant to this study because the Navy must make correct decisions regarding watch schedules and crew sizes with the newer classes of ships.

In another study, Arendt, Middleton, Williams, Francis, and Luke (2006) studied a group of watchstanders and day workers to assess the differences in fatigue. In this study, 14 watchstanders on a four hours on, eight hours off schedule were compared with 12-day workers. Among the watchstanders, some were on a fixed schedule, i.e., they stood the same watch at the same time every day, while others were on a shifting schedule. The results of this study showed that among the watchstanders whose schedules rotated, sleep quality was significantly less than those in the other groups. The researchers postulated that this may be due to the disruption of circadian rhythms of the rotating watchstanders in question, who had difficulty adapting to the constantly shifting schedule. Additionally, they found that watchstanders on the fixed schedule had much more restful sleep than either of the other groups.

Sawyer (2004) examined the effects of reversing the sleep/wake cycles of the crew of the USS John C. Stennis (CVN-74). Her study provides a solid understanding of the effect of shift work in a military environment. Sawyer’s study found that reversing the sleep/wake cycles of the Sailors could affect mood, anger, depression, and a host of other issues. What this study notes is that when Sailors deploy, they might be going from a normal “work during the day/sleep at night” schedule to the opposite “work at night/sleep during the day.” Sawyer (2004) notes that while human circadian rhythms can adjust to changes in schedule, it takes time for this adaptation to be accomplished. During

this period of adjustment, military personnel might be asked to participate in combat or other operations, making clear the need for restful, effective sleep.

Osborn (2004) explains that many vessels in the U.S. Navy are on a three-section watch rotation, i.e., five hours on watch, followed by 10 hours off watch, and then the cycle repeats. As a result, Sailors are never on watch at the same time in any given series of days. One day they may be working at night, and the next day in the morning, etc. This type of shiftwork, common in both the Surface and Sub-Surface Navy, can lead to a serious sleep debt and impair overall performance.

Prior to Osborn, Stolgitis (1969) examined the differences in sleep effectiveness yielded by two different watch schedules: a four hours on/eight hours off schedule, and a six hours on/12 hours off schedule. Stolgitis found that the six/12 schedule provided sailors with the greatest opportunity for continuous, uninterrupted sleep. While eight hours of sleep is generally considered ideal for humans, the eight hours provided for by the four/eight system do not seem to take into account that sailors have many more duties than simply standing watch. By the time a given watch is completed, Sailors must find time to perform divisional duties and take part in drills, not to mention eat. After all of these activities, there is far less than eight hours left for sleep before the next watch. Figure 13, taken from Stolgitis (1969), illustrates these findings. A major problem with the Stolgitis study is that humans have tremendous difficulty in adjusting to an 18-hour day, i.e., one in which “morning” occurs every 18 hours . USN Submariners who adopted his solution continue to struggle with 18-hour day length. The white areas refer to time available for sleep.

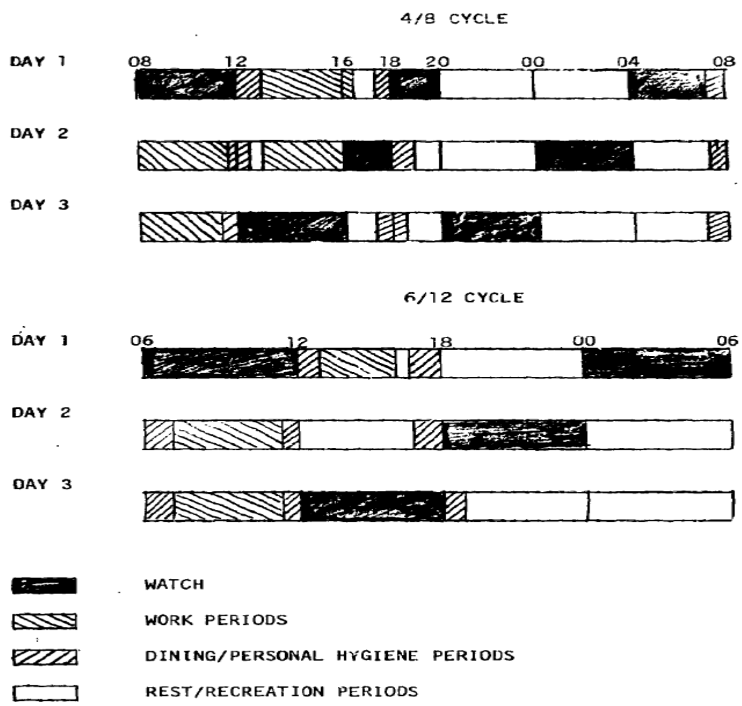

Figure 13. 4/8, 6/12 Watch Schedules (from: Stolgitis, 1969)

F. MOTION

Stevens and Parsons (2002) discussed the various effects that shipboard motion has on Sailors' ability to perform their assigned tasks. While the study puts a great deal of emphasis on the performance of activities and motion, some attention was given to the effects that motion has on sleep, and, consequently, on crew performance as a result of the impacted sleep. They suggest that the manner in which crew quarters are designed and laid out has an impact on the quality of sleep in rough seas and weather. If intense motion prevents adequate sleep, either due to its sheer violence, or to seasickness, crew performance will suffer. Stevens and Parsons (2002) further explain that altering the layout of crew berthing may allow for more effective sleep during inclement weather.

Archibald (2005) explained that the HSV-2 Swift, a high-speed catamaran, is meant to simulate what had been a possible design for the LCS. This vessel is capable of speeds of up to 42 knots, and carries a crew of about 40 Sailors. Archibald noted that due to the relatively small crew size of these new ships, just one Sailor stricken with seasickness would have a far greater effect than it would on the ships currently in service.

One of the primary areas of focus in Archibald's study was the effect of motion on sleep. Archibald's work is important because this issue is, in part, the focus of our study. Additionally, McCauley, Miller and Matsangas (2004) wrote that the Sailors aboard the Swift reported that motion was the fourth greatest factor affecting sleep.

Calhoun (2006) postulates that ship motion can have a significant effect on sleep effectiveness. He notes that Sailors sleeping on the lower decks of a ship, as close to the centerline as possible, have the best chance of getting restorative sleep and being the least affected by motion. Calhoun (2006) goes on to note that many ships, specifically merchant ships, have the superstructure of the ship, which includes the bridge and crew quarters, on the aft end. He explains that this is the worst possible location for them and that shipbuilders do not take this important factor into account. Figure 14, taken from Calhoun (2006), illustrates how motion is a contributing factor when it comes to sleep.

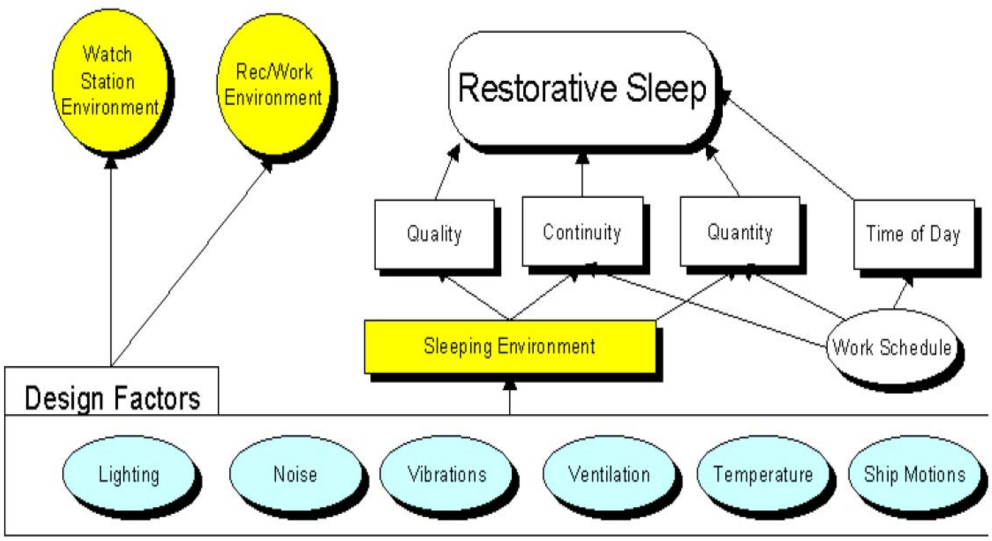

Figure 14. Motion as a Sleep Factor (from: Calhoun, 2006)

G. VIBRATION

Ship vibration is closely related to motion. This thesis examines the effect of sleeping surfaces on sleep quality. A key component of this thesis is to assess what type of mattress can best reduce the vibration caused by the ship's interaction with the ocean

while moving at different speeds. The ABCD Working Group (2008) created a graph that simplifies the relationship between the vibration and shock of high-speed craft (HSC) and crew performance, shown is Figure 15.

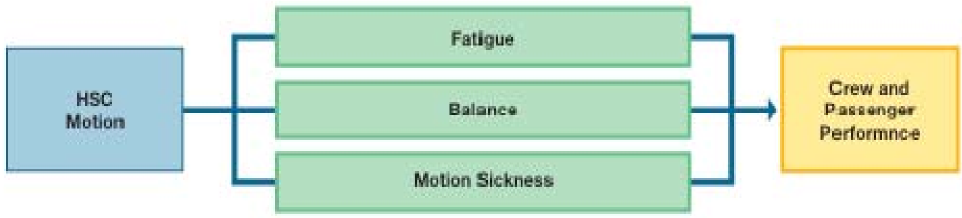

Figure 15. HSC Motion and Crew Performance (from: ABCD Working Group, 2008)

Calhoun (2006) claims that vibration, among other factors, can prevent the human body from reaching the deeper levels of sleep necessary for a restorative experience. Often times, a person exposed to excessive vibration will remain in stage two of the sleep cycle, according to Calhoun. Figure 16, taken from Calhoun (2006), illustrates this point. Calhoun's point is reinforced by a study conducted by Arnberg, Bennerhult, and Eberhardt (1990). In this study, the researchers constructed a vibration table and placed it beneath a room in which the participants slept. The goal of the experiment was to ascertain whether noise and vibration would have a different effect on sleep patterns than noise alone. They found that sleep was significantly more disturbed when noise was combined with vibration.

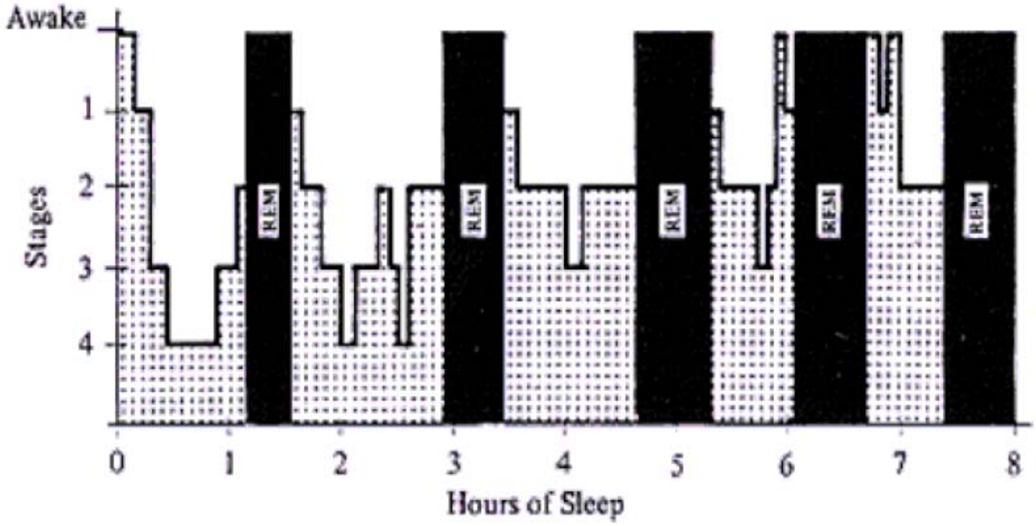

Figure 16. The Sleep Cycle (from: Calhoun, 2006)

Figure 16 represents the four stages of human sleep and the amount of time a person might spend in each stage over the course of eight hours. According to Sleepdex.org (2009), the four stages include light sleep (Stage 1), when a person can awaken several times and can be very easily disturbed. During Stage 2, brain waves decrease and a person’s eye movement comes to a halt. In Stage 3, standard brain waves are mixed with delta waves. In Stage 4, the deepest level of sleep, brain waves are entirely of the delta variety. As a corollary to this, REM sleep, shown in Figure 16, is interspersed amidst the other stages. During REM sleep, the eyes move rapidly and there is frequent muscle movement. REM sleep is often the stage in which people dream. Figure 17, taken from Sleepdex.org (2009), gives examples of the brain waves that occur during these stages.

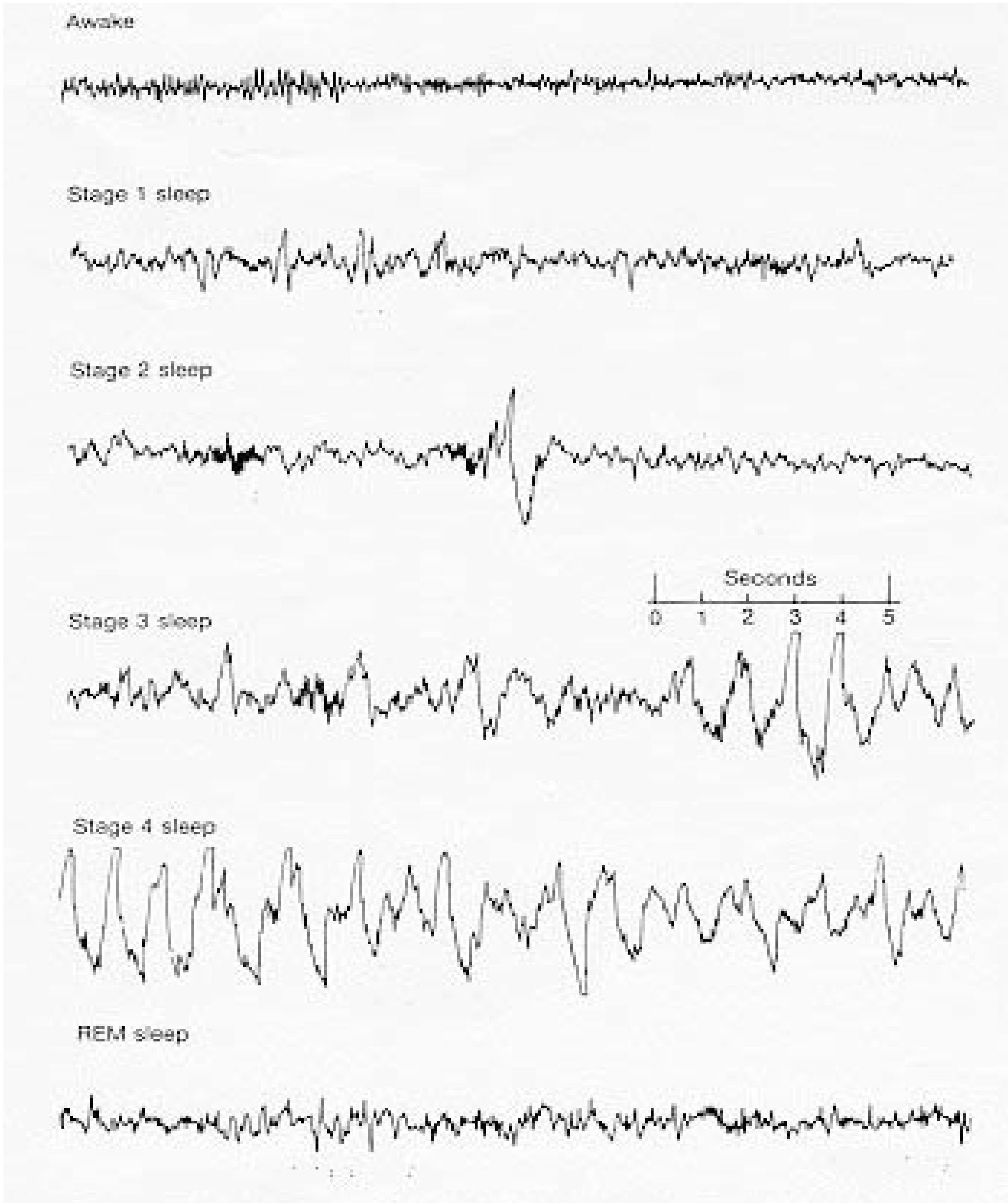

Figure 17. Brain Waves During Sleep (from: Sleepdex.org, 2009)

However, the effects of vibration are not limited to sleep efficiency. According to Mabbott, Foster, and McPhee (2001), extended exposure to vibration can cause a host of physical injuries, including muscle and skeletal problems, circulatory issues and a general feeling of discomfort. Mabbott et al. (2001) also suggest that there may be a linkage between vibrations experienced by two-crew truck drivers and sleep loss. While they submit that there is no conclusive evidence to support this claim, they suggest that further

research is warranted. While this study was focused on truck drivers, much of its logic can be applied to mariners, which underscores the need to have sleeping surfaces that can help to reduce the transfer of vibration to the body. Admittedly, the vibrations experienced by truck drivers are not the same as those experienced by Sailors. However, the salient point is that vibration is a factor worth consideration. Not only might Sailors lose sleep due to vibration, but long-term injuries may result as well.

Dobbins, Rowley and Campbell (2008) explain that the shock and vibration caused by high-speed craft (HSC) can be broken into two basic categories. Table 5, taken from Dobbins, Rowley and Campbell (2008), explains these categories in greater detail.

Type	Description of Environment
I	The environment is predominantly characterized by repeated shocks or transient vibrations (e.g. wave impacts of high speed crafts) and may contain some underlying vibration. Exposure can be of any duration.
II	The environment is characterized as predominantly sinusoidal in nature, where occasional shocks or transient vibrations are present. Exposure can be of any duration.

Table 5. Categories of Motion Related to Shock (from: Dobbins, Rowley, and Campbell, 2008)

Additionally, Dobbins, Rowley and Campbell (2008) note that vibration typically has its greatest affect on humans when it is between 0.05-80 HZ. Table 6 further illustrates what happens to the human body at various levels of vibration.

Frequency (Hz)	Effect
0.05 – 2	Motion sickness, peak incidence occurs at ~0.17 Hz
1 – 3	Side-to-side and fore-and-aft bending resonances of the unsupported spine
2.5 – 6	Strong vertical resonance in the vertebrae of the neck and lower lumbar spine[2]
4 – 6	Resonances in the trunk[1]
20 – 30	Resonances between head and shoulders[1]
Up to 80 Hz	Localised resonances of tissues and smaller bones

Table 6. Vibration Effects on the Human Body (from: Dobbins, Rowley and Campbell, 2008)

Dobbins, Rowley and Campbell (2008) also explain that how shock and vibration are dealt with is highly dependent on the nature of the ship's mission. They explain that the designers of vessels that are required to travel at high speeds in virtually all sea states must take greater steps to reduce the damaging effects. It follows that the converse is true, i.e., vessels that travel at high speeds only on occasion will require less vibration mitigation. Dobbins, Rowley and Campbell (2008) suggest a variety of methods for shock mitigation, including specially designed seats, examples of which are provided in Figures 18-19.

Figure 18. Bolster Seat (from: Dobbins, Rowley and Campbell, 2008)

Figure 19. Suspension Seat (from: Dobbins, Rowley, and Campbell, 2008)

According to Nakashima (2004), low-frequency vibration is capable of causing sleep disturbance in that it can make a person more conscious of other environmental factors. Nakashima (2004) also notes that one of the ways that vibrations might be reduced would be to alter the design of seats. While her work focused on land-based travel, the same principle could be applied to the racks onboard Navy ships. By altering the sleeping surface, vibrations might very well be reduced, allowing for better sleep quality.

H. MEASURES OF SLEEP

Section I (PILOT STUDY) will discuss the pilot study that preceded this thesis effort. However, before explaining that study, it is necessary to elaborate on some of the various methods used to measure sleep and its effects. One tool for analyzing sleep is FAST, or the Fatigue Avoidance Scheduling Tool. According to Novasci.ms11.net (2005), FAST uses the data gathered by a wrist activity monitor (WAM), which will be discussed in greater detail in a following section. The WAM records motion while a participant wears it. FAST then uses this data and incorporates sleep/rest cycles and circadian rhythms to assess predicted effectiveness in the conduct of various activities. Furthermore, FAST is based on the Sleep, Activity, Fatigue, and Task Effectiveness model (SAFTE), developed by Steven Hursh. According to Hursh et al. (2004), SAFTE

does not account for a number of variables, such as stimulants in the body, but it is still widely accepted in the Department of Defense as an effective method for measuring sleep. Figure 20, taken from Hursh et al. (2004), illustrates how the SAFTE model works.

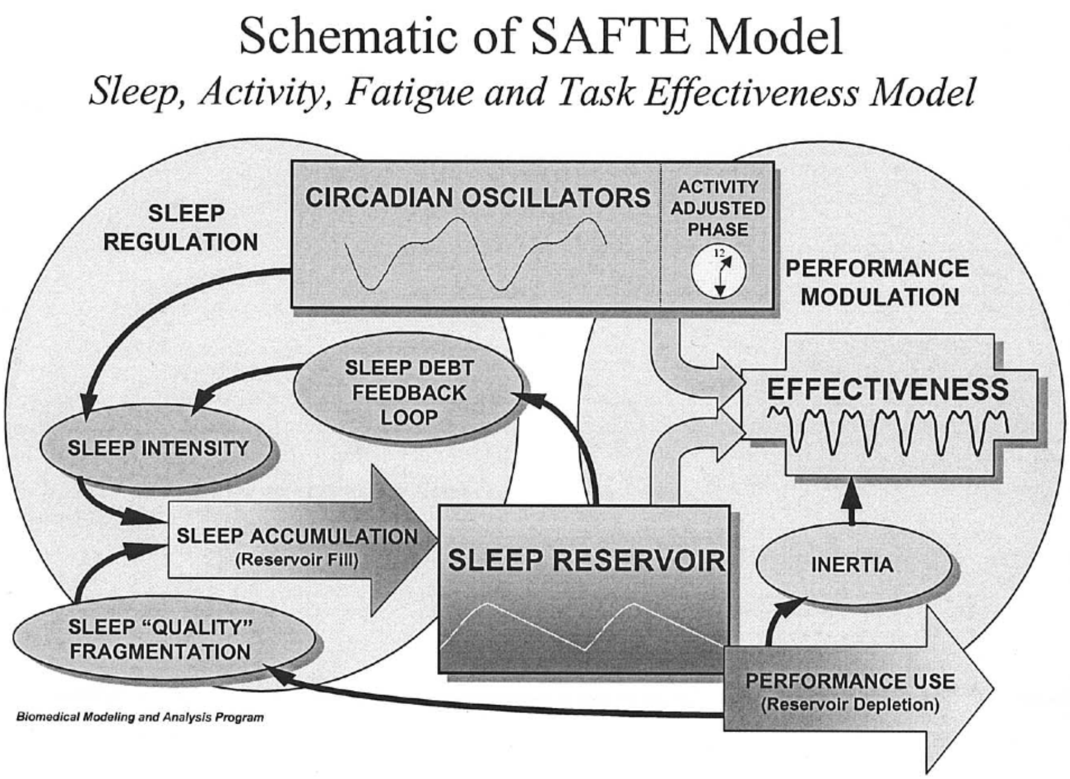

Figure 20. SAFTE Model (from: Hursh et al., 2004)

Although not utilized in this thesis, polysomnography is another important method for measuring sleep and sleep related issues. According to the U.S. National Library of Medicine and the National Institutes of Health (2009), polysomnography uses a series of electrodes attached to the chin, scalp and eyelids of the participant. In addition, heart rate and breathing patterns are also monitored. This method, which is far more intricate and advanced than the methods used in this thesis, is able to draw a number of conclusions regarding the sleep patterns and efficiency of a given participant. For example, it is possible to ascertain specific sleep stages and examine the changes in respiration and body temperature.

I. THE PILOT STUDY

During a class project in the fall of 2008, Grow and Sullivan conducted a pilot study to test the feasibility of using a motion platform to test sleep quality and quantity. The goal of the study was to see if the equipment and computer software would support the expanded study covered in this thesis. The participants for the pilot were two graduate students, also the authors of the current thesis. They used a computer controlled, three-motor motion platform capable of simulating pitch, roll and heave. The platform was controlled through the use of LabView software which used motion data obtained during a motion-related study conducted on the USS SWIFT (HSV-2). The platform was not able to completely simulate ship motion, however. In particular, it was only able to simulate heave (vertical displacement) from one to four inches. The SWIFT is a high speed, catamaran-style vessel that may well have motion properties similar to the warships of the future. Figure 21, taken from the report on the pilot study by Grow and Sullivan (2009), illustrates how the inputs into LabView are arranged.

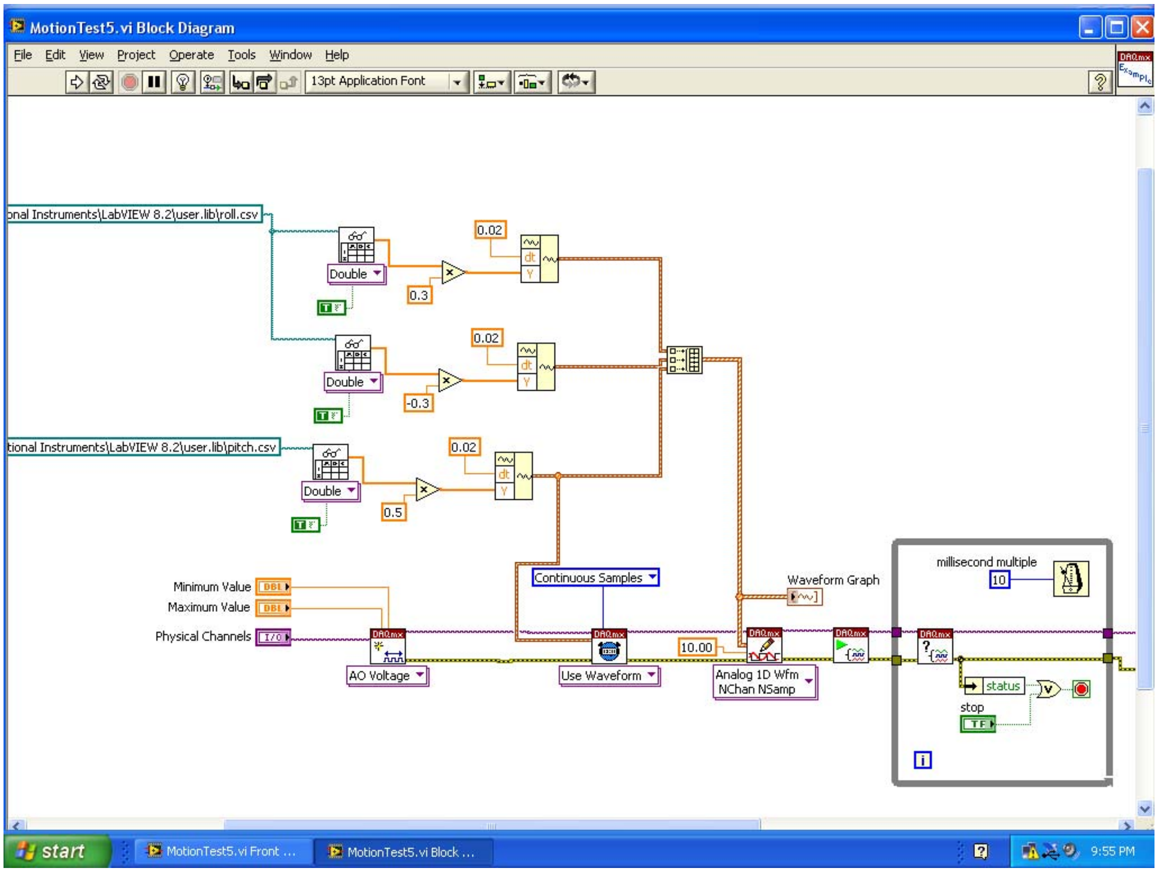

Figure 21. LabView (from: Grow and Sullivan, 2009)

The pilot study was conducted over the course of two nights in which one participant slept on the motion platform, while the other slept on the stationary mattress on the floor in the same laboratory. During the week leading up to the data collection, both participants wore a WAM, which contains an active memory to record motion data for up to 45 days. The participants continued to wear the WAMs during the experiment. A third WAM was also attached to the motion platform as a means of comparing the motion of the platform with that of the participant.

Figures 22–25 show the actigraphy data for both participants. Once data collection was complete, the data were analyzed using the FAST software program. While the results could not be statistically analyzed, due to the small sample size (n=2), the authors did find the differences between sleep on the motion platform and sleep on

the ground. These results lead the authors to conclude that the basic methods were viable and that the expanded study, conducted for this thesis, should proceed.

In addition to actigraphy data, both participants were required to keep a sleep/wake journal to record when they slept, when they rested and when they worked. This data was used to mark periods of time in the actigraphy data. Though not required for the pilot study, participants in this thesis study were asked to also fill out a post-experiment questionnaire, designed to obtain subjective data on sleep quality.

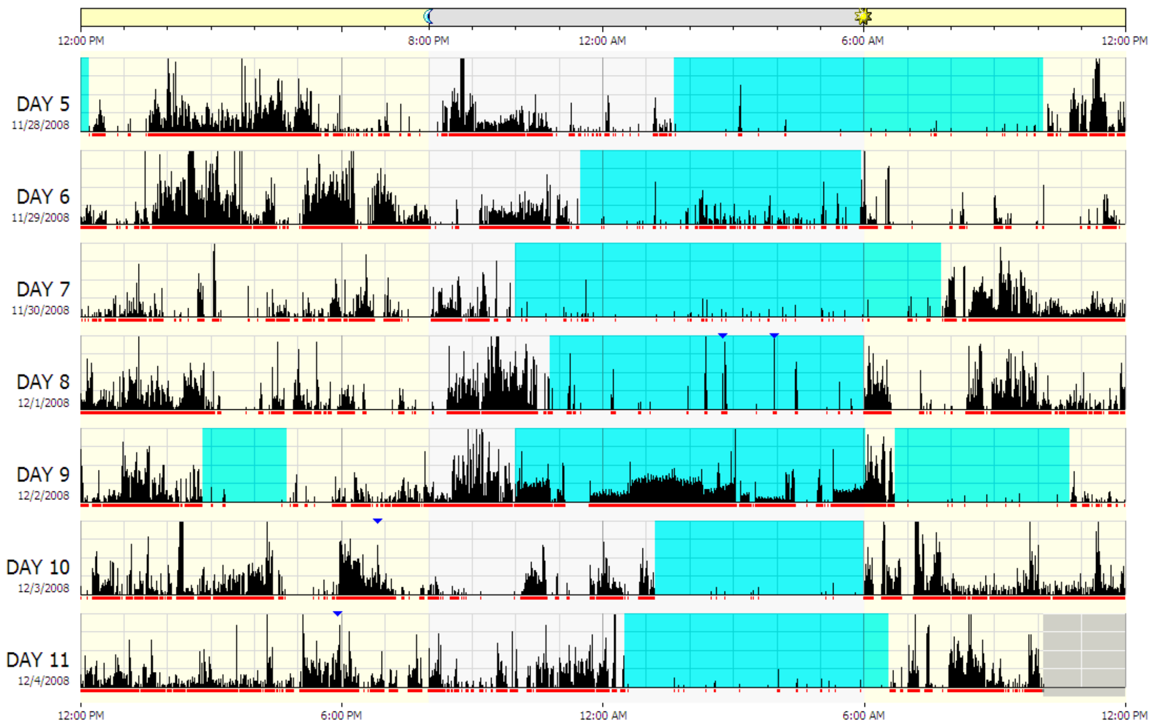

Figure 22. Participant One Actigraphy Data (from: Grow and Sullivan, 2009)

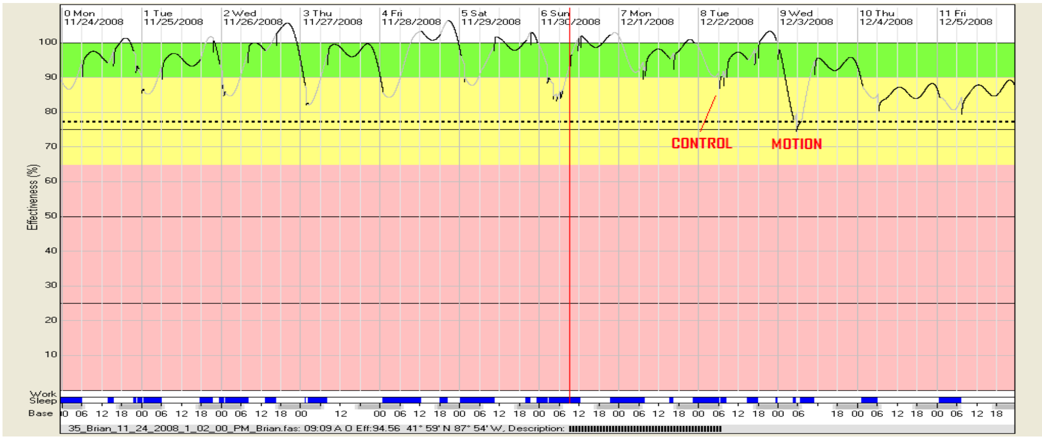

Figure 23. Participant One FAST Data (from: Grow and Sullivan, 2009)

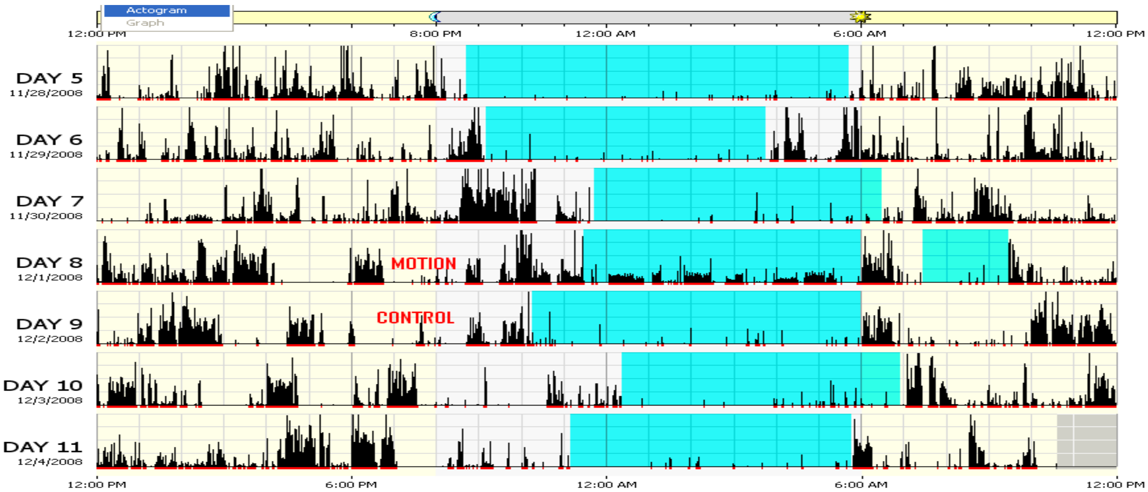

Figure 24. Participant Two Actigraphy Data (from: Sullivan and Grow, 2009)

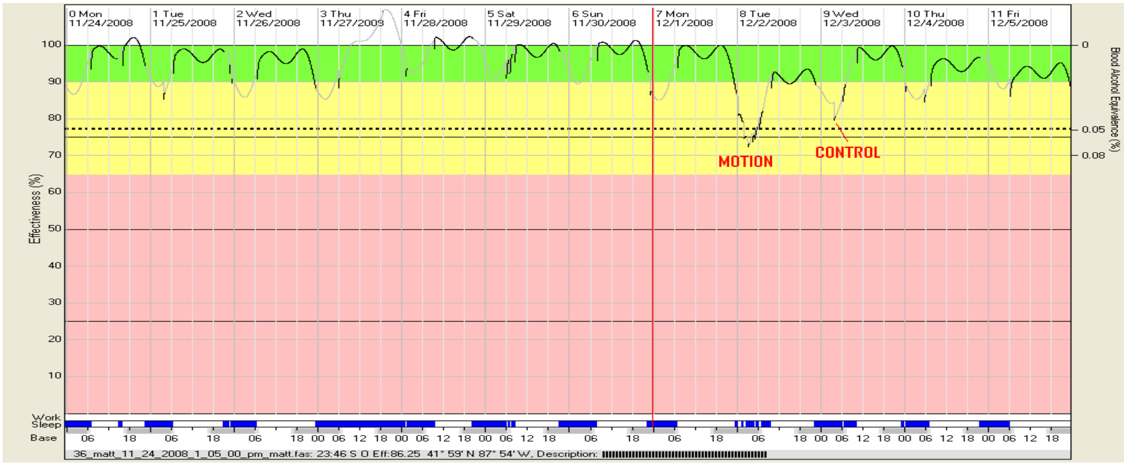

Figure 25. Participant Two FAST Data (from: Sullivan and Grow, 2009)

J. SLEEP SURFACE

A major variable that can affect an individual's quality of sleep is the sleeping surface or mattress. Since much of our lifetime we spend sleeping on mattresses, it is surprising that more attention has not been given to this important aspect of sleep. The Navy eventually realized the effect that improved mattresses could have upon sleep in shipboard berthing spaces. In June of 2000, the Secretary of the Navy proposed a plan to replace the standard foam core mattresses with new and improved innerspring mattresses. The new mattresses are an inch thicker than the previously used foam mattresses and provide more support to promote proper spinal column alignment. According to Defenselink.mil (2000), the new mattresses were widely accepted by Sailors over the foam core mattresses during a test conducted onboard the USS Cole (DDG-67). The second major question of this thesis examines whether or not high-quality visco-elastic foam mattresses can provide more comfort and support than the innerspring mattresses currently used onboard U.S. Navy ships.

NASA originally developed visco-elastic foam in 1966 for use in airplane seat cushions because of its superior shock absorption and comfort properties. However, this was just the beginning for many uses of this space-age material. It has been used as padding in protective helmets, offered superior comfort in high-tech footwear, and provided relief to hospital patients suffering from pressure ulcers, according to NASA (2005). This material is now commercially used to manufacture mattresses for sale to the general public. Perhaps the Navy and its Sailors can also benefit from visco-elastic foam mattresses.

Currently, there have only been a handful of studies that objectively compare different types of mattresses. Lee and Park (2006) accomplished this by measuring skin temperature and with polysomnography, which utilizes electroencephalography (EEG) equipment as well as other devices. They used these objective measures as well as a subjective mattress rating system to determine the effects of uncomfortable and comfortable mattresses on sleep quality. A comfortable mattress was defined as one that supports the spinal column in order to achieve alignment that closely mimics the curvature of a standing position. Significant differences were found between the

mattresses with relation to the participants' sleep stage composition percentage, as seen in Figure 26. A significant difference was also found between skin temperatures with higher temperatures being found when participants slept on the comfortable mattresses. More deep sleep (S3+S4) was seen with the comfortable mattress.

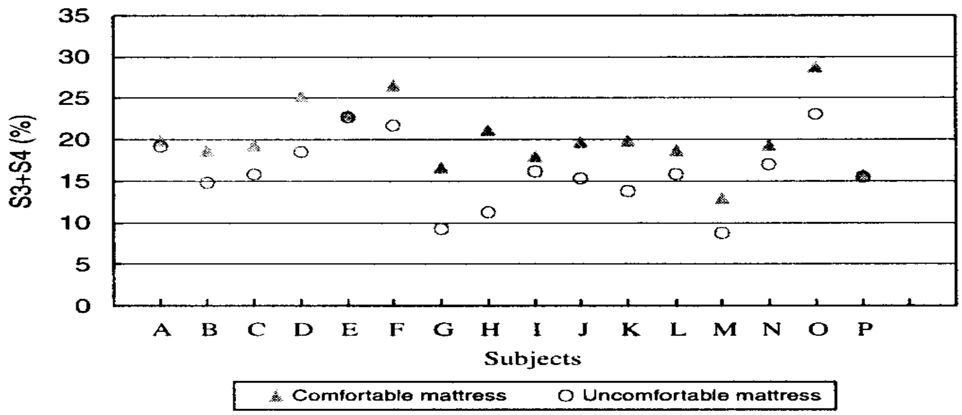

Figure 26. Comparison of mean percent-stage of slow-wave activity (from: Lee and Park, 2006)

In another study, DeVocht et al. (2005) used a biomechanical method to evaluate the differences between mattresses. They stated that at the time, there had been extensive advertising promoting proper spinal alignment with certain mattresses as compared to others. However, there were no quantitative metrics to determine the exact differences. Their study utilized a system of landmarks placed on the spine as confirmed by a chiropractor. These marks were placed on the bare skin of the participants and their positions were recorded using a digital camera. The participants' spinal alignment was recorded across four different mattresses. Pressure-sensitive pads were also used to determine the 10 highest-pressure areas of each mattress. There were no statistically significant results found between the mattresses with respect to spinal distortion. However, it should be noted that the four mattresses being used were all considered to be top-of-the-line queen-size mattresses. The study by DeVocht et al., (2005) did demonstrate an objective way of measuring the differences between mattresses.

Scharf et al., (1997) also conducted research comparing standard mattresses to experimental foam surfaces. They objectively compared the different mattresses by

measuring sleep architecture and the Cyclical Alternating Patterns (CAPs) of each participant. This data was collected using advanced polysomnography equipment. While their results showed no statistically significant differences between total sleep time, sleep stages, or number of awakenings, they did find that CAP rates were significantly reduced on the experimental foam surface. The first-night effects were also somewhat reduced on the foam surface as compared to the innerspring mattress.

While this thesis will utilize somewhat less advanced equipment than previous research, the authors realize the importance of combining objective measures with subjective feedback from the participants. Even small differences between mattresses can greatly improve sleep efficiency and the quality of life aboard Navy ships, making further research a worthwhile endeavor.

III. METHODS

A. PARTICIPANTS

1. Selection

Potential participants were contacted through a mass email to the Naval Postgraduate School (NPS) community that explained the basic requirements of the study. This email can be found in Appendix G. Interested participants were asked to meet with the researchers to fill out a series of three questionnaires designed to rule out sleep disorders. The first questionnaires were the Epworth Sleep Quality survey and the Motion History questionnaire. These two surveys examined potential participants' susceptibility to sleep disturbance and motion sickness. The researchers then examined the results for abnormalities that might disqualify a potential participant. These abnormalities included a high susceptibility to motion sickness, as well as a difficulty sleeping in new locations. If they met the criteria of the two initial surveys, they were given a third questionnaire, the Pittsburgh Sleep Quality Index (PSQI). The PQSI provides more detailed information on individual sleep habits that might affect the study data. Once all three surveys were completed, the participant was cleared to participate in the study. This was necessary because not all personnel would be able to effectively tolerate the conditions of the study. For example, some people have a great deal of difficulty sleeping in a new environment for the first time. This condition is sometimes known as "hotel room syndrome." Since the study was conducted in a laboratory, hotel room syndrome was a potential confound factor, adversely affecting the results. Second, each participant was exposed to strong vibrations and jarring motions during Phase 2 of the experiment. For this reason, the researchers preferred to use participants who had at least some experience on naval vessels. Personnel with this experience would be better suited to withstand the intense motions created by the motion platform. Additionally, the researchers sought to eliminate any person who was prone to motion sickness. It was hoped that personnel with shipboard experience would be able to effectively cope with extreme motion. Copies of the three questionnaires are provided in Appendix B.

The exact grading of the three surveys was done in the following ways: For the MHQ, the grading was not based on a score, but rather on responses to key questions. If a participant reported any sort of extreme response to one of the questions, he or she was disqualified. For example, respondents who responded that they always feel seasick when onboard a ship, they were disqualified. If, however they responded that they only rarely, or never experienced seasickness, they were cleared to continue. While this may not be the most precise methodology, this survey was intended to eliminate only those who were highly susceptible to motion sickness. The Epworth Sleepiness Scale survey was graded by simply adding up the scores. If a participant's score was from one to eight, he or she was considered to have no significant sleep issues. Respondents whose scores were nine or above were considered to have serious sleep issues and were disqualified from the study. Finally, the PQSI asked participants to rate their sleep habits using a scale ranging from zero to three. The scores were summed and if a score was 10 or higher, that person was deemed to have significant sleep issues and was disqualified from the study. Any score below 10 was considered acceptable.

2. Demographic Makeup

The participants in this study were 12 military officers, all students at the Naval Postgraduate School in Monterey, CA. Of these 12, 11 were male and one was female. Ages of the participants ranged from 26-40 years. All participants had spent time at sea on U.S. Naval vessels.

B. MATERIALS

1. Software

a. FAST

The FAST program constituted a large part of this data analysis. This program (based on the SAFTE model discussed in Chapter II) allowed the authors to take into account the work/rest cycles of the participants, as well as their circadian rhythms, and then used this data to predict effectiveness at various tasks. Figure 27, taken from Maynard (2008), illustrates the types of data that FAST generates and what those results indicate.

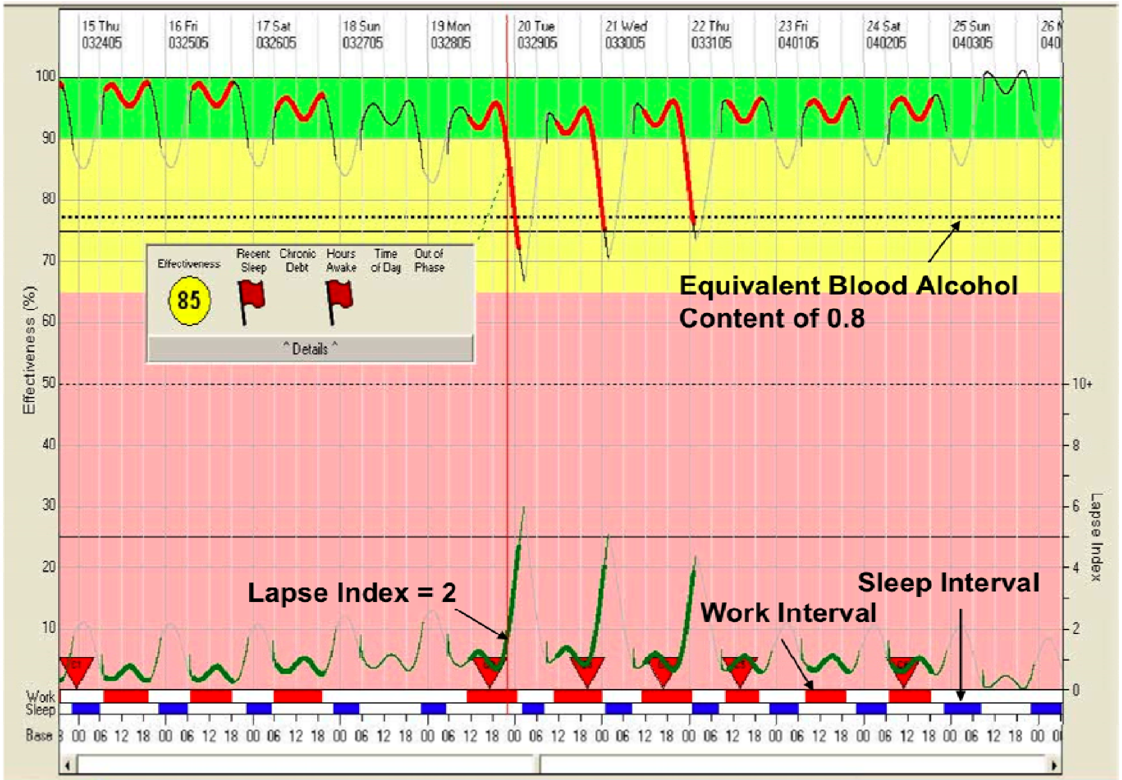

Figure 27. FAST Data (from: Maynard, 2008)

From this example of one participant over a 10-day period, one can see how predicted effectiveness can be decreased to the point where it is equivalent to a person who is legally intoxicated. Additionally, sleep and work intervals are marked by time and date over the course of the data collection period. This tool provides an excellent indication of how sleep, or lack thereof, can positively or negatively affect performance.

b. Actiware

The Actiware program was a primary source of data analysis for this study. The program is designed to work in concert with the WAMs in that it displays the data collected in chronological order, and then calculates sleep efficiency. The program uses an Actireader, shown in Figure 28. The WAM, shown in Figure 29, is placed on the communications pad and the motion data is transferred to the computer.

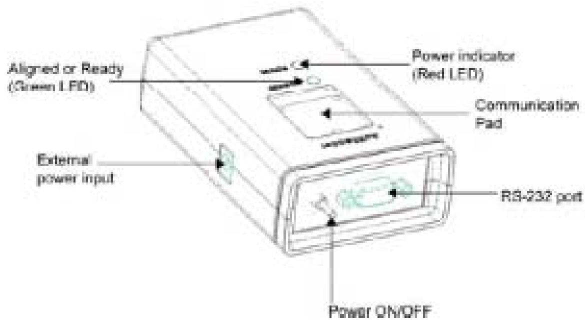

Figure 28. The Actireader (from: Actiwatch Instruction Manual, 2008)

Figure 29. WAM (from: UC Berkeley Web site, 2009)

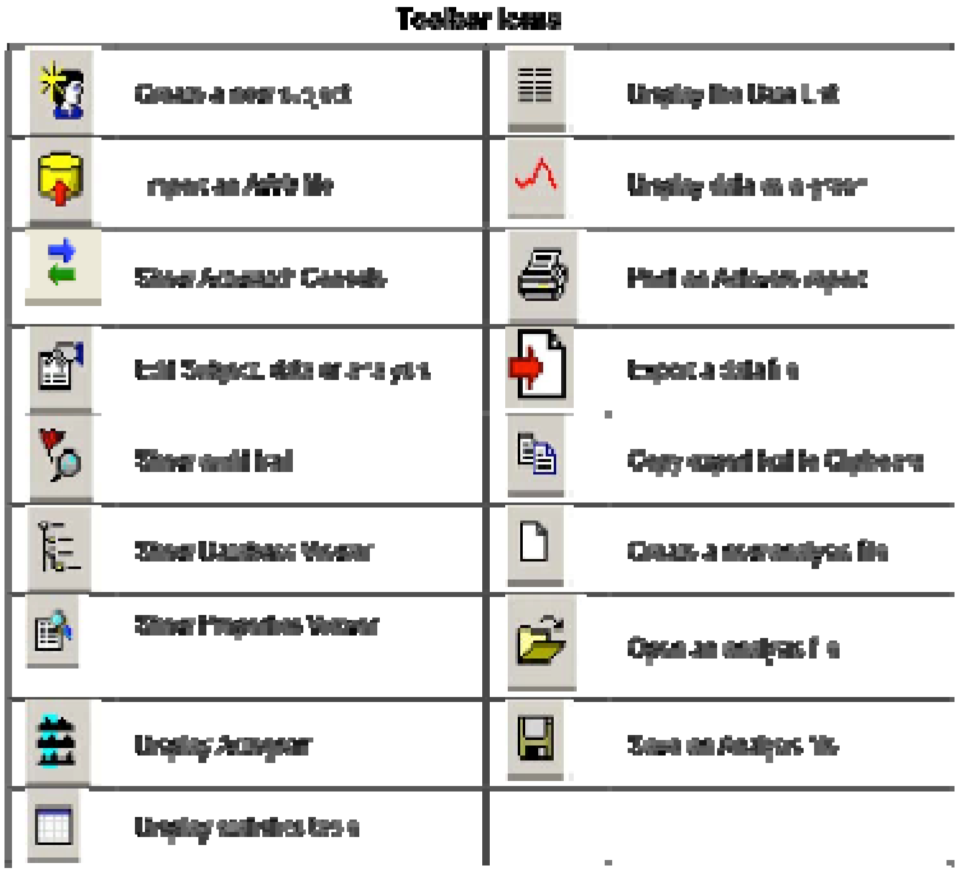

Figure 30. Actiware Tool Bar (from: Actiware Instruction Manual, 2008)

The user has several options, which are shown in Figure 30. The basic process is to create a new subject, which requires the wearer's age and gender, as well as the start time for data collection. Once the data are downloaded for a specific participant, the actigraphy data can be used by selecting one of the options, outlined in Figure 31.

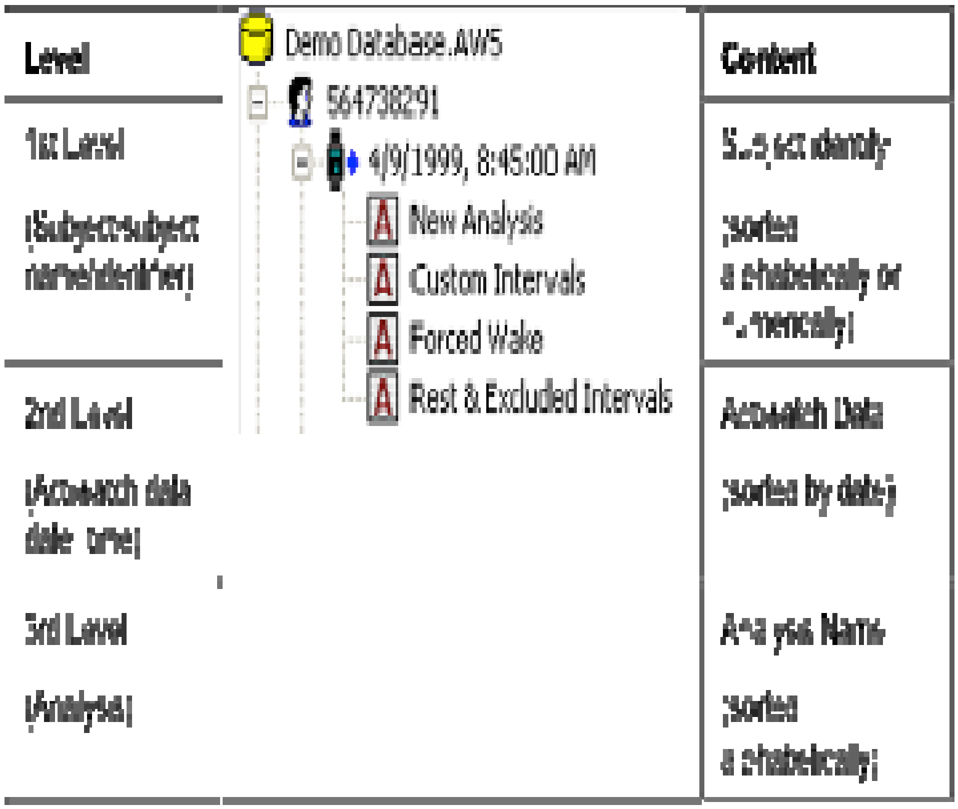

Figure 31. Actiware View Options (from: Actiware Instruction Manual, 2008)

c. *LabVIEW*

The LabVIEW program is a graphical programming system. By inputting the data obtained from the USS SWIFT (HSV-2), the software used a type of logic flow chart to control the motion machine, effectively telling the motors how and when to move. An example of this motion profile is provided in Figure 21. The data from the SWIFT were obtained through the use of accelerometers placed throughout the ship. Table 7 shows the data in its raw form.

HEADER	TimeStamp	Vert Bow Accel Port	MK27 Roll Angle	MK27 Pitch Angle	MK27 Roll Rate	MK27 Pitch Rate
SCAN RATE		100				
EU SLOPE	0	1.333333	1	1	1	0
EU OFFSET	0	0	0	0	0	0
V SLOPE	0	0.000245	1	1	1	0
V OFFSET	0	0.215093	0	0	0	0
DATA	23	25	BRICK1	BRICK1	BRICK1	BRICK1
COMEX	0	0.064657	-0.274658	-0.079651	-0.401001	-0.001373
	0.1	0.064004	-0.293135	-0.08015	-0.349315	-0.049838
	0.2	0.064004	-0.323547	-0.090912	-0.231812	-0.155457
	0.3	0.064004	-0.335693	-0.132141	-0.074921	-0.310516
	0.4	0.064004	-0.335693	-0.132141	-0.074921	-0.310516
	0.5	0.064004	-0.335693	-0.132141	-0.074921	-0.310516
	0.6	0.064004	-0.335693	-0.132141	-0.074921	-0.310516
	0.7	0.064004	-0.291481	-0.331306	0.348644	-0.720978
	0.8	0.064004	-0.254333	-0.401825	0.458405	-0.824112
	0.9	0.061608	-0.154358	-0.556641	0.547028	-0.86499

Table 7. Sample of LabVIEW Data

Through the program, modifications could be made to increase or decrease the intensity and speed of the motions. The program operates on a standard Windows-driven PC, and was controlled by one of the researchers.

2. Equipment

a. Motion Machine

The principle piece of equipment for this study was the motion machine. This machine, which was originally developed for use in a driving simulator, uses 220-volt power to drive three separate motors. Each motor is responsible for a single axis of motion, two angular and one linear. One motor controls pitch, one controls roll and the third controls heave. It is capable of +/- 40 degrees of roll and can move from limit to limit (80 degrees) in one second. Pitch range is limited to plus or minus six degrees and heave is up to four inches. While these limitations do not allow the full range of possible shipboard motion, they are sufficient for an initial analysis of motion/stationary and comparison of mattress types. The limited heave motion does not simulate ship motion, indicating that further research will be needed in full motion. In addition to the machine

itself, certain additional modifications were made to the research set-up. A series of steel beams were attached to form the base of the mattress platform. A plywood board was attached to the top of these beams.

One of the additional features of the motion machine is the emergency stop system. This was composed of two push buttons that could stop the machine immediately. One button was attached to one of the metal beams, which ran the length of the plywood board. This button was to be used by the participant, should he experience any discomfort, or simply feel uneasy about continuing the experiment. The second button was placed at the observer's station, and was to be used by the researcher, should any problems be detected, or if the participant appeared to be in any danger. Additionally, flipping a switch on the power unit could stop the machine. Figures 32-35 show the machine, motors, as well as the locations of the emergency stop switches.

Figure 32. The Motion Machine

Figure 33. Motion Machine Directional Motors

Figure 34. Machine-Mounted Emergency Stop Switch

Figure 35. Researcher's Emergency Stop Switch

b. Stable Platform

For the stable, stationary surface, the researchers used a standard military cot. This allowed the participant to be at approximately the same height as the participant on the motion machine.

Figure 36. Stable Platform

c. Actiware WAM

The WAM was the principal data collection tool. This device is worn like a wristwatch and is able to record the number of motions of the wearer that exceed a threshold. Using the Actiware program, which was discussed in greater detail in a preceding section, the authors were able to trace the work/rest patterns of the 12 participants and interpret the data to determine the level of sleep efficiency. Each participant was required to wear a WAM for one week prior to the laboratory sleep sessions to form a baseline for their sleep patterns at home. Each participant was required to keep an activity log of when they slept and worked (school work or manual labor). It also allowed for the participants to record the consumption of caffeine, alcohol, and the use of tobacco, all of which could affect sleep.

d. Motion Cube

The motion cube is a small device manufactured by Intersense. According to the Intersense Web site (2009), it is capable of measuring acceleration along three axes

(yaw, pitch, and roll) and has an angular range of 360 degrees in all three axes. Additionally, it has a maximum angular rate of 1200 degrees per second, a minimum angular rate of 0 degrees per second, and updates data at a rate of 180 HZ.

e. Visco-Elastic Foam Twin-Sized Mattress:

The visco-elastic foam was originally developed by NASA as a means of relieving the pressure that astronauts experienced during liftoff, according to Tempur-Pedic™ Management Inc. (2009). Figures 37 and 38, taken from the Tempur-Pedic Web site, illustrate how this material alleviates pressure.

Figure 37. Human Body on a Tempur-Pedic Mattress (from: Tempur-Pedic™ Management, Inc., 2009)

Figure 38. Human Body on a Standard Mattress (from: Tempur-Pedic™ Management Inc., 2009)

The orange and red colored areas in Figure 38 represent pressure points on the body, points that are absent in Figure 37. Judging by the pressure points, the visco-elastic material may be effective at reducing the shock and vibration experienced by participants on the motion machine, and thus be worthy of further analysis as a viable alternative to the traditional Navy mattress.

f. Standard Navy Rack Mattress

A standard innerspring mattress was the second sleeping surface. It is very similar to what is used currently onboard Navy ships. Unfortunately, due to contractor requirements and timeframe constraints, the authors were unable to obtain the exact model being used by the Navy. Instead, a mattress comparable in price, construction, and dimension was substituted.

C. VARIABLES

1. Independent Variables

The independent variables for this experiment were mattress type and motion condition. As previously stated, mattress type includes the standard Navy rack mattress and a twin-sized visco-elastic foam mattress. The two motion conditions are simply defined as motion and stationary. Mattress type is a between-subjects variable, while motion condition is a within-subjects variable, creating a two-by-two mixed factorial design.

2. Dependent Variables

The dependent variables for this experiment were objective sleep efficiency, subjective sleep efficiency, predicted effectiveness, and transmitted shock. Objective sleep efficiency was measured by the WAMS and interpreted by the Actiware program. This information provided an objective assessment of the efficiency of sleep obtained by each participant. Subjective sleep efficiency was based on a post-experiment survey administered to each participant. This survey asked the participants to rate the quality of sleep that they obtained. Both objective and subjective means of sleep efficiency were collected to ascertain if the two measures are correlated. Predicted effectiveness was a

measure of how well a participant will perform a given task after a certain type of sleep as was measured by the FAST program. Finally, the transmitted shock variable refers to the number of motion events that were transmitted from the machine through the mattress. We measured this by using two WAMS. One WAM was attached to the machine, while the other rested on top of the mattress. For this variable, there were no participants and both mattress types were used on the machine while the catamaran motion input program was running. Additionally, a motion cube was used to assess the level of acceleration transmitted through the mattresses.

D. PROCEDURE

The procedure for this study was divided into three phases. Phase One was the selection and screening of participants. Phases Two and Three were counter balanced. Phase Two required each participant to sleep on either the visco-elastic foam or standard Navy mattresses in one of the two motion conditions. In Phase Three, the motion condition was switched for each participant, while the type of mattress used remained the same.

1. Participants

Once Institutional Review Board (IRB) approval was received**,** participants from NPS were solicited via an email, a copy of which is provided in Appendix F. Interested personnel were then interviewed and asked to complete three questionnaires to ascertain their suitability for the study. Once a participant was deemed suitable for the study, he or she was given a WAM and asked to wear the device for a period of seven days while carrying out their normal schedule. Additionally, each participant was asked to maintain a schedule of his or her everyday activities. This schedule, a copy of which is provided in Appendix C, records when each participant worked, rested, and slept, etc. The purpose of this seven-day period was to establish a baseline from which sleep efficiency could be ascertained. By using the schedule, we were able to divide each participant's activities into work, rest, and sleep in the Actiware program.

A seven-day period was required at minimum to establish a proper baseline, but some participants exceeded this time frame. To compensate, only the seven days prior to

the actual data collection were used. This was to allow for maximum scheduling flexibility, as the participants had a number of other demands on their time.

2. Sleep Exposure

With the participants selected, Phase 2 of the study began. This phase encompassed the heart of the study. Each participant was randomly assigned a sleeping surface, either a standard Navy mattress, or a visco-elastic foam mattress by means of a coin toss. Because the mattress condition followed a between-subjects design, participants were limited to only one of the two surfaces. Ideally, the sleeping surface condition would have been within subjects, but time constraints forced us to make an adjustment and block on mattress type.

Once a participant had been assigned to a sleeping surface, he or she spent a single night on either the stationary surface or on the motion platform. Since both motion conditions were to be experienced by each participant, a coin toss randomly selected which condition would be used first. Once sleeping surface and motion condition were confirmed, each participant spent eight hours sleeping in the laboratory. The time chosen was from 10 p.m. until 6 a.m. This schedule is in accordance with the time allotted for sleep in the NSWW. One of the potential confounds was the day of the week. For example, a participant who slept in our laboratory on a weeknight might experience less efficient sleep than a participant who slept in the laboratory on a weekend night. Because of the excessive time commitments required for participation in this study, the researchers were forced to accept this as a justifiable risk. To counter this, at least in part, we attempted to schedule both nights either during the workweek or on the weekend.

For the stationary sleep condition, participants were instructed to lie down on their assigned sleeping surface a few minutes before 10 p.m. Participants were asked to continue to wear their WAM and to dress in their normal sleeping attire. They were allowed to bring their own pillow and/or blanket if they wanted. While one might assume that these items should be kept constant, it is important to note that on a ship, Sailors are allowed to furnish their own pillows and blankets. If participants chose not to use their own pillows and blankets in the laboratory, they were provided with clean linens by the

researchers. The primary advantage of conducting this study in a laboratory setting was that the researchers were able to control light, temperature, and sound to a large extent. To this end, the room temperature was maintained between 65 and 75°F. With regard to light, the aim was to keep the laboratory as dark as possible. The sole limitation in this regard was the need to keep a single computer screen active in order to monitor the LabVIEW program. Additionally, during the course of the night, at least one of the researchers was required to be present in the laboratory to monitor the participants, ensuring both a safe environment as well as the correct functioning of the equipment.

Once each participant had completed a night in the stationary condition, he or she was required to sleep on the same sleeping surface, but this time on the motion platform, or vice versa. The procedure for this part of the experiment varied slightly. The conditions in the laboratory were maintained as they were during the stationary condition to ensure uniformity. In addition to the WAM worn by the participant, a second WAM was attached to the motion platform. The addition of the second WAM allowed for the isolation of the motion of each participant from the motion of the platform. This information was compared during the analysis phase in the Actiware program.

Once the participant had settled onto the platform, the researcher observing the experiment for that night activated the motion machine and then activated the LabVIEW program. The program, which has been described in detail, provided an input signal based on motion data obtained from experiments previously conducted on board the USS SWIFT. In order to ensure participant safety, a series of mats were placed on the floor around the motion machine. In the event that the participant fell off of the platform during the night, the risk of injury would be minimal. The LabVIEW program was set to recycle in order to provide the illusion of constant and consistent shipboard motion.

Once the second night of data collection was completed, the participant’s role in the experiment was finished. The procedure utilized for participants assigned to the visco-elastic mattress was identical to the procedure outlined above.

Finally, each participant was asked to fill out a post-experiment survey the morning after their second night in the laboratory. This survey was designed by the

researchers and asked the participants to subjectively rate the quality of sleep obtained during the two nights of data collection. It was hoped that this set of subjective data would provide a secondary frame of reference that would either support or contradict the objective data.

3. Vibration Assessment

Once all of the data had been collected, the WAMS were returned to the researchers for the extraction of the data. Prior to data analysis, another form of data collection took place. The purpose of this phase of the study was to determine the relative amount of shock and vibration transmitted from the motion machine through the mattresses. First, the standard Navy mattress was placed on the machine and one of the WAMs not used in the previous phases was attached to it. Then, a second WAM, also not used in the previous phases, was attached to the base of the machine, below the mattress, and the machine was activated and run for a full cycle, which lasts for 20 minutes. By comparing the data from the two WAMs, the researchers were able to ascertain the levels and the amount of shock and vibration transmitted through the mattress. The process, outlined above, was then repeated with the visco-elastic foam mattress. The researchers were then able to compare the two sets of data to determine if there was a significant difference between the number of motion events transmitted through the two types of mattresses. Additionally, a motion cube was used to obtain acceleration data. To achieve this, the cube was placed on a sandbag, weighing 7.5 pounds. The sandbag was placed on the platform in the approximate location of a participant's head and the motion program was run for a complete cycle, which lasted 20 minutes. This process was repeated for each mattress type.

4. Sleep Data Analysis

Data from the WAMs were downloaded using the Actiware program to ascertain sleep efficiency during the control, motion, and stationary portions of the experiment. The daily activity logs, which participants filled out during the seven days prior to the laboratory sleep phase, were used to divide time into work, rest, and sleep. Upon completion of the actigraphy analysis, the data were imported into the FAST program.

FAST allowed the researchers to ascertain the predicted task performance effectiveness for each participant. Finally, the data collected from the post-experiment surveys were analyzed in order to compare subjective data with the objective data from the WAMs actigraphy and the predicted effectiveness.

5. Method of Analysis

To assess the results of this study, a one-way ANOVA was used to determine if there was a significant difference in sleep efficiency due to motion condition and mattress type. For shock and vibration, WAMs were utilized to obtain activity counts and a motion cube was used to obtain acceleration data. Finally, a survey was used to obtain subjective data from the participants. The survey data was analyzed using a Wilcoxon Rank Sum test.

After each participant completed two nights in the laboratory, they were asked to complete a survey to provide subjective data on sleep quality, as well as on shock and vibration that they experienced. The survey was divided into two sections, one for each mattress type, with six questions in each. For each question, there was a five-point Likert scale and participants were asked to select only one answer per question. The six questions were essentially identical, with only the mattress type differing. In order to discern if there was a statistically significant difference in the responses between the two mattress types, as well as the two motion conditions, the corresponding questions from each section were compared using a Wilcoxon Rank Sum test. The following sections compared motion versus stationary conditions. Next, comparisons were made across the two groups. Only the comparisons with differences deemed significant were reported in this chapter. A full recounting of the results can be found in Appendix E.

To analyze vibration, the activity counts were compared simply to see with which mattress type they were higher. For the motion cube acceleration data, the numbers for each axis (X,Y, and Z) were used to calculate the Root Mean Square (RMS). The RMS were then compared to see which condition had the highest numbers, indicating that less vibration was absorbed by the mattress.

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IV. RESULTS AND ANALYSIS

A. OVERVIEW

Participant demographics are discussed in Section B. Section C covers summary statistics, as well as the tests used to determine if the motion/stationary order was significant. Section D provides an example of the type of actigraphy data that was collected during the study. Section E contains the statistical analysis of the sleep efficiency data. Section F recounts the results of the post-experiment survey. Section G describes the results of the shock and vibration tests. Finally, Section H covers predicted effectiveness.

B. GENERAL STATISTICAL INFORMATION ON PARTICIPANTS

Participant	1	2	3	4	5	6	7	8	9	10	11	12
Age	27	26	31	34	39	28	32	43	35	34	35	25

Table 8. Participant Ages

The average age of study participants was 32.42, with a standard deviation of 5.40. While this is a considerable range, they are representative of the age range one would most likely find on a U.S. Navy warship, including the officers and crew. Additionally, 11 of the participants were male, and one was female. The researchers would have liked to have more female participants, but were limited by time constraints, and the difficulty encountered in recruiting participants.

C. SUMMARY STATISTICS AND ANALYSIS OF ORDER EFFECT.

Table 9 provides the summary statistics for sleep efficiency in the baseline, motion and stationary conditions. The order column refers to the order in which each participant slept in the motion/stationary conditions. A one in this column indicates that that participant slept in the motion condition during the first night in the lab. The S/E columns are percentages that represent sleep efficiency, as generated by the Actiware program. B/L stands for baseline, referring to the seven days prior to laboratory data

collection. Two point of interest present themselves: first, stationary sleep efficiency was higher in ever case than the baseline. Second, motion sleep efficiency was zero or nearly zero in almost every case.

Participant #	Age	Gender	Order	Mattress Type	B/L AVE S/E	Motion S/E	Stationary S/E
1	27	M	1	VE	53.7	0.0	79.8
2	26	M	1	VE	72.0	0.0	95.8
3	31	M	1	VE	77.2	48.1	90.4
4	34	M	2	VE	82.3	0.0	93.1
5	39	M	2	VE	67.1	0.0	85.4
6	28	M	2	VE	78.3	0.0	91.5
7	32	M	1	ST	83.5	2.3	88.5
8	43	M	1	ST	89.4	2.7	94.6
9	35	F	1	ST	67.9	0.0	83.7
10	34	M	2	ST	78.3	0.0	91.4
11	35	M	2	ST	75.3	0.0	77.1
12	25	M	2	ST	79.8	0.0	99.8

Table 9. Sleep Efficiency Statistics

Table 10 provides additional summary data, including mean, standard deviations, minimum and maximum values for sleep efficiency.

	Baseline Sleep Efficiency	Motion Sleep Efficiency	Stationary Sleep Efficiency
Mean	75.4	4.4	89.3
STDEV	9.3	13.8	6.7
MIN	53.7	0.0	77.1
MAX	89.4	48.1	99.8

Table 10. Summary Statistics

Since the order in which participants slept in the two motion conditions varied, the researchers had planned to test for the existence of an order effect. (In every case, the two days of sleep were consecutive, so a subject who slept poorly the first day on the motion platform might have been expected to sleep well the second day.) However, since almost every measurement of sleep efficiency in the motion condition was near zero, no test for order effect was performed.

D. ACTIGRAPHY DATA AND SLEEP EFFICIENCY

In the following actigraphs, labeled Figures 39–41, the black lines represent motion, captured by the WAM. The green areas represent periods of rest, while the blue

areas represent periods of sleep. The actigraphy for the remaining 11 participants can be found in Appendix A. The figures for participant one are provided purely as an example, and to explain the different elements contained within.

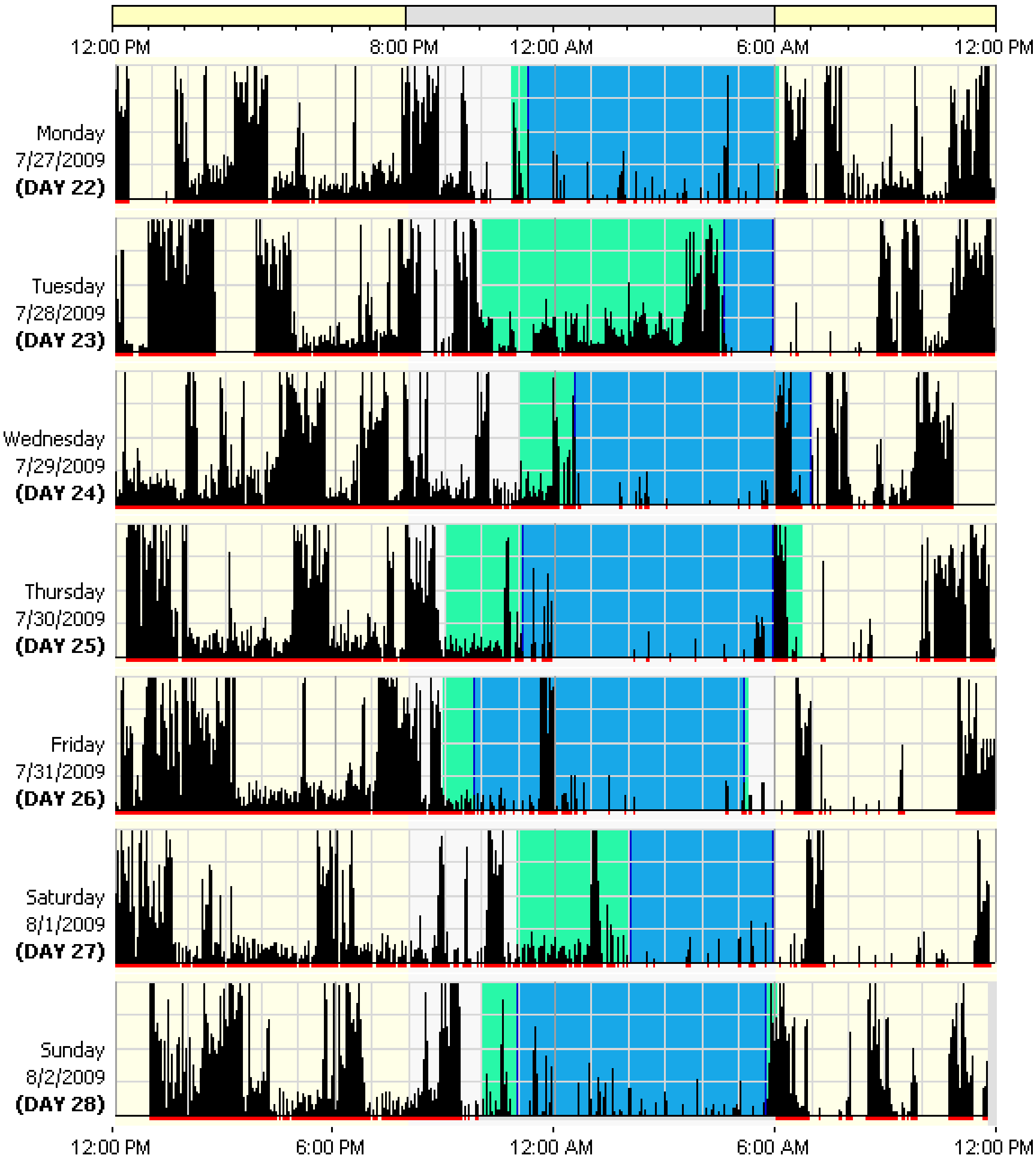

Figure 39. Participant One Baseline Actigraphy Data (Control)

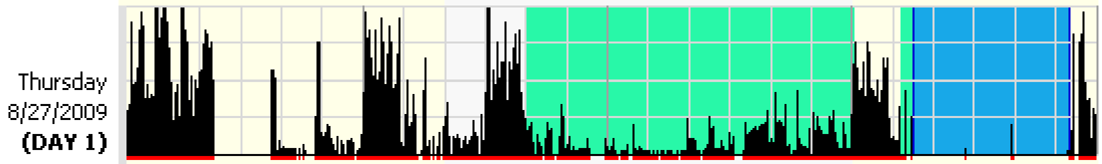

Figure 40. Participant One Motion

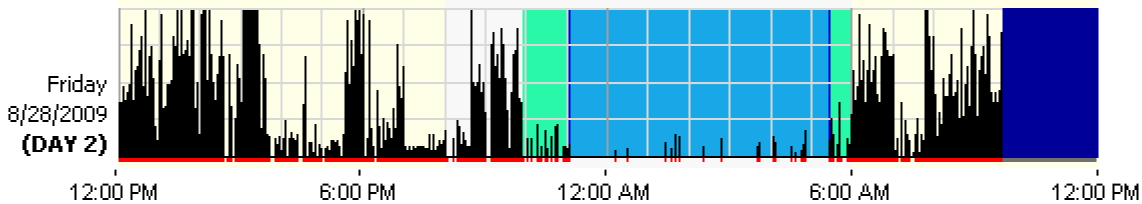

Figure 41. Participant One Stationary

E. SLEEP EFFICIENCY STATISTICAL RESULTS

Since the motion sleep efficiencies were substantially smaller in every case than the stationary ones, the conclusion that motion sleep efficiency is less than stationary sleep efficiency (in the population from which the current sample is assumed to be drawn) is clear. Formally, a one-sided sign test produces a *p*-value of .0002, so the hypothesis that motion sleep efficiency is as likely to be higher than stationary efficiency as lower is rejected.

Second, stationary sleep efficiency was compared across mattress types. Lacking evidence of Normally distributed populations, the researchers used the Wilcoxon Rank Sum test. Here the hypothesis that stationary sleep efficiency has the same level for the two mattress types cannot be rejected ($p = .94$).

Finally, stationary sleep efficiency was compared across order (whether the motion condition was encountered first or second) using the paired version of the Wilcoxon Rank Sum test. The hypothesis that the two order conditions produced the same level of stationary sleep efficiency cannot be rejected ($p = .84$).

F. SURVEY RESULTS

1. Mattress Type and Motion Versus Stationary Condition Compared to Sleep at Home

Survey questions 1 and 2 were given to participants who slept on the standard mattress in the laboratory (*n*=6). Survey questions 7 and 8 were given to participants who slept on the V/E mattress in the laboratory (*n*=6). The questions and responses are listed below. The hypothesis is that participants experienced better sleep quality in the stationary condition compared to the motion condition in each mattress condition.

1. Compared to how you normally sleep at home, please rate how you slept on the standard Navy mattress in a zero-motion condition.

Much Worse	Worse	About the Same	Better	Much Better
1	2	3	4	5

2. Compared to how you normally sleep at home, please rate how you slept on the standard Navy mattress in the motion condition.

Much Worse	Worse	About the Same	Better	Much Better
1	2	3	4	5

7. Compared to how you normally sleep at home, please rate how you slept on the visco-elastic mattress in the stationary condition.

Much Worse	Worse	About the Same	Better	Much Better
1	2	3	4	5

8. Compared to how you normally sleep at home, please rate how you slept on the visco-elastic mattress in the motion condition.

Much Worse	Worse	About the Same	Better	Much Better
1	2	3	4	5

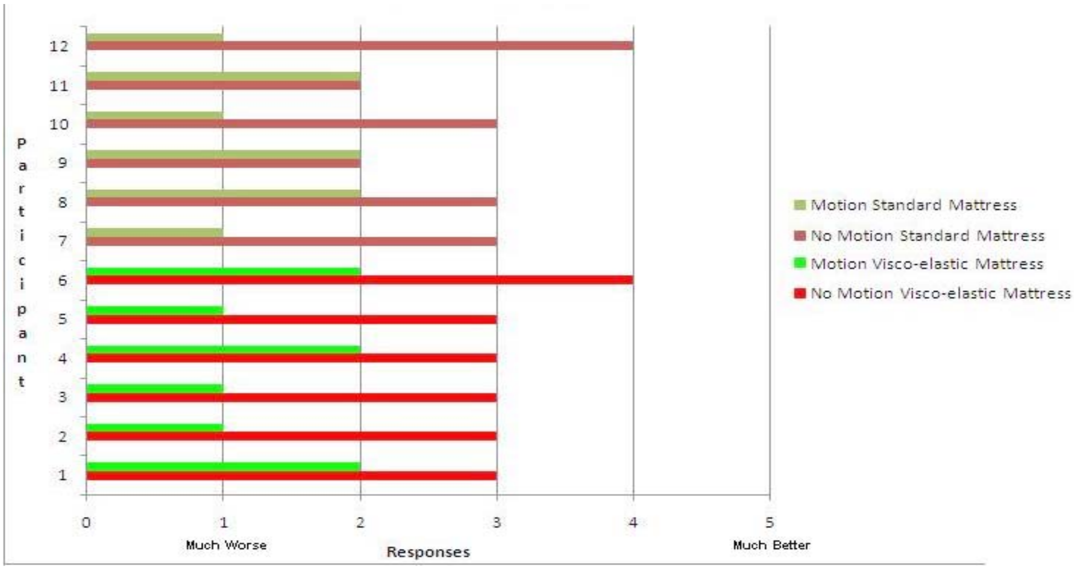

Figure 46. Questions 1, 2, 7, 8 Responses by Participant

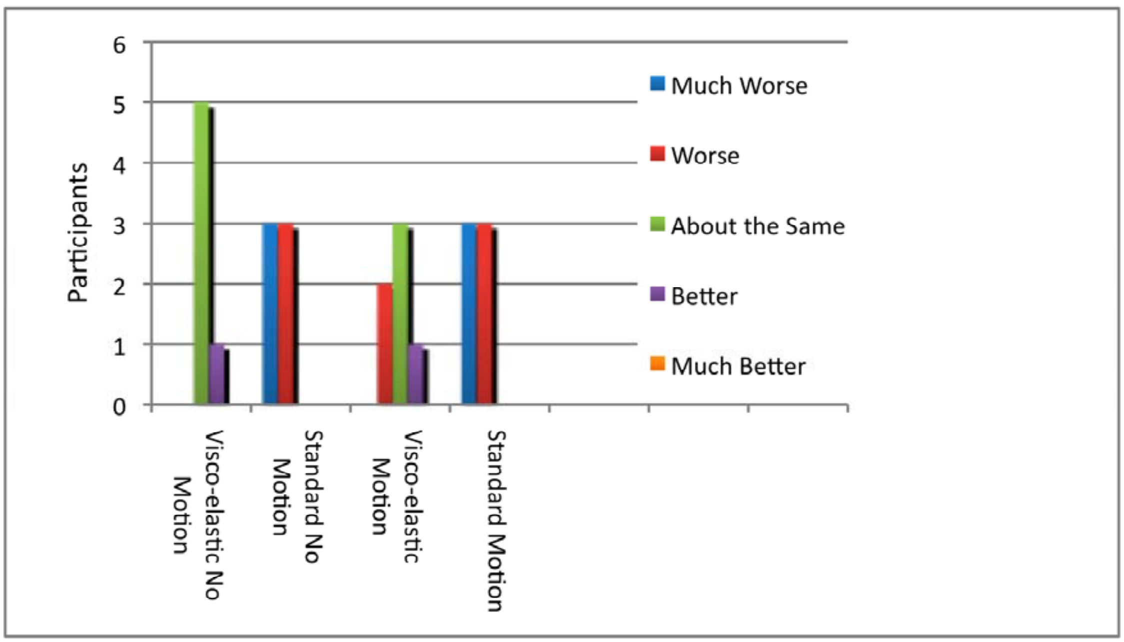

Figure 47. Questions 1, 2, 7, 8 Responses by Group

Test Statistic	10.5
p Value	0.03

Table 11. V/E Wilcoxon Rank Sum Test Questions 7 and 8

According to the data in Table 11, there is a significant difference in responses to questions 7 and 8 that is a *p* value of .03 which is less than the alpha of .05.

2. Mattress Type and Motion Versus Stationary Conditions

Participants (*n*=6) rated how well rested they felt after sleeping on the standard mattress in the motion and stationary conditions (questions 5 and 6). Those individuals who slept on the V/E mattress (*n*=6) were asked questions 11 and 12. The questions and responses are listed below. The hypothesis is that participants felt more rested after sleeping on the V/E mattress in both mattress conditions.

5. Please rate how well rested you felt after sleeping on the standard Navy mattress in a stationary condition.

Extremely Well	Very Well	Moderately Well	Well Rested	Not Well Rested
1	2	3	4	5

6. Please rate how well rested you felt after sleeping on the standard Navy mattress in the motion condition.

Extremely Well	Very Well	Moderately Well	Well Rested	Not Well Rested
1	2	3	4	5

11. Please rate how well rested you felt after sleeping on the V/E mattress in a zero motion condition.

Extremely Well	Very Well	Moderately Well	Well Rested	Not Well Rested
1	2	3	4	5

12. Please rate how well rested you felt after sleeping on the V/E mattress in the motion condition.

Extremely Well	Very Well	Moderately Well	Well Rested	Not Well Rested
1	2	3	4	5

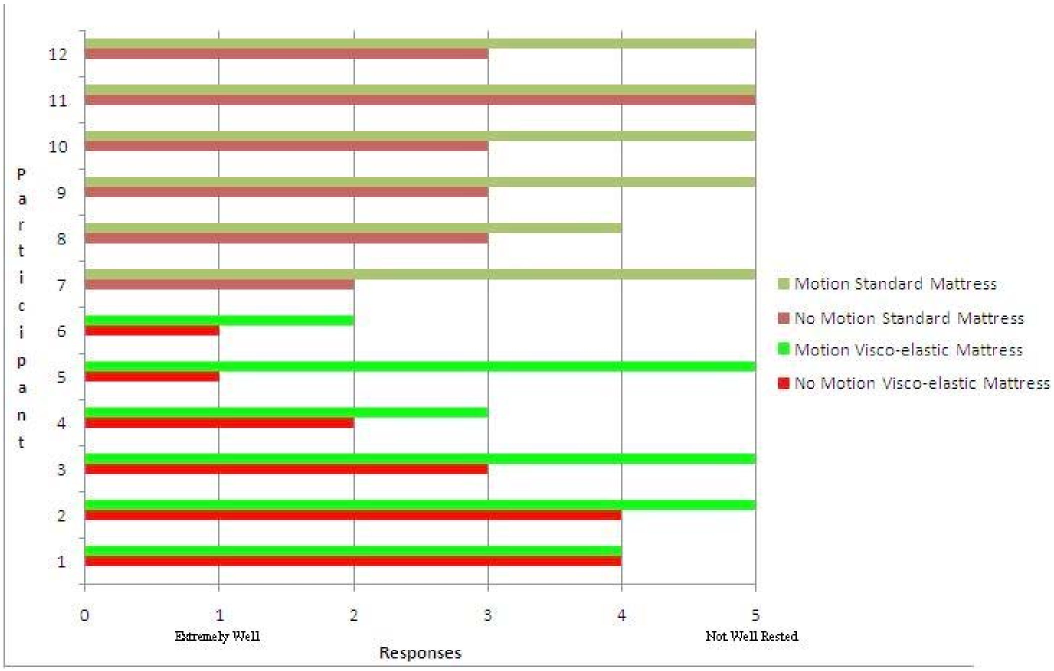

Figure 48. Questions 5, 6, 11, 12 Responses (Primary)

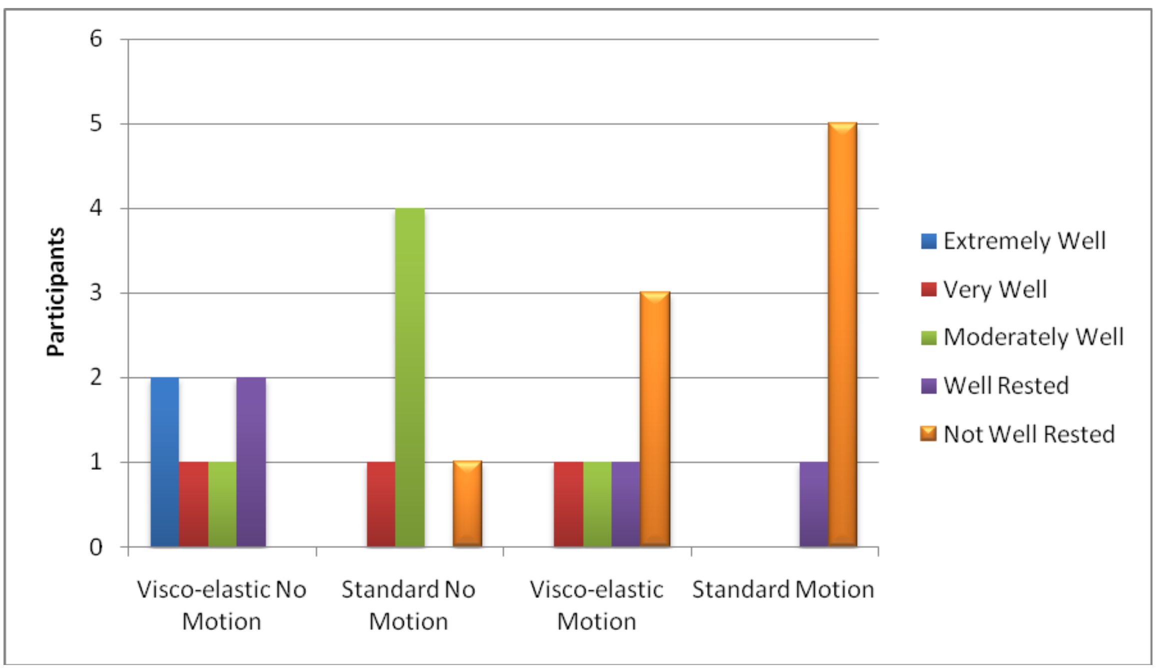

Figure 49. Questions 5, 6, 11, 12 Responses (Secondary)

Test Statistic	7.5
p Value	0.06

Table 12. Wilcoxon Rank Sum Test Questions 5 and 6

This analysis indicates a *p* value of .06, which is just short of the alpha of .05. This indicates that there is not a significant difference between participant responses to these two questions, although the stationary condition tended to produce more rested personnel.

11. Please rate how well rested you felt after sleeping on the visco-elastic mattress in the stationary condition.

Extremely Well	Very Well	Moderately Well	Well Rested	Not Well Rested
1	2	3	4	5

12. Please rate how well rested you felt after sleeping on the visco-elastic mattress in the motion condition

Extremely Well	Very Well	Moderately Well	Well Rested	Not Well Rested
1	2	3	4	5

Test Statistic	7.5
p Value	0.06

Table 13. Rest Assessment Wilcoxon Rank Sum Test

The responses to questions 11 and 12 do not show a significant difference, although the *p* value of .06 suggests that a larger number of participants might yield a significant result.

G. VIBRATION DATA

1. Activity Counts

While the post-experiment survey did touch on the subject of shock and vibration, the researchers wanted to obtain a set of empirical data as well. While previous research in this area utilized more advanced tools, this study was limited in terms of equipment availability. Therefore, in order to obtain vibration-like data, the researchers placed a WAM on the center of the motion platform, below the mattress. The standard mattress was then laid on the platform and a second WAM was placed at its center, directly on top

of the first WAM. The machine was activated and allowed to run through one full cycle (20 minutes). The researchers repeated this process with the V/E mattress. The data were then fed into the Actiware program to obtain activity counts, the results of which are provided in Table 14.

WAM Location	Activity Count
Platform With No Mattress	1359
V/E Mattress	809
Standard Mattress	11562

Table 14. Activity Counts

These results indicate that a great deal of the motion generated by the machine was absorbed by the V/E mattress. Conversely, the motion seems to have been amplified by the standard mattress. The V/E mattress appears to be far more effective at reducing vibration than the standard mattress.

Comparing this data to the survey results concerning shock and vibration, we see a definite relationship. We stress that these results are not statistically significant, but the survey results, taken together with the vibration data are highly suggestive of differences between the two mattress types. Therefore, further research should be conducted with a larger sample size. It seems quite possible that, given a larger sample size, there would be a statistically significant difference in the amount of shock and vibration perceived by the participants across the two mattress types.

2. Motion Cube

Cube Location	X Axis (m/s/s)	Y Axis (m/s/s)	Z Axis (m/s/s)
Platform Only	.51	1.35	9.81
Standard Mattress	1.08	2.00	9.65
V/E Mattress	.99	1.45	9.73

Table 15. Linear RMS Acceleration (meters/second/second)

Cube Location	Pitch (deg/sec)	Roll (deg/sec)
Platform Only	2.36	5.63
Standard Mattress	2.04	8.63
V/E Mattress	.87	5.73

Table 16. Angular RMS Velocity for Pitch and Roll (deg/sec)

Table 15 shows the RMS acceleration data in the three linear axes, generated by the motion cube, while Table 16 shows the RMS velocity for pitch and roll.

Figure 50 shows acceleration in the Z-axis for each of the three conditions (platform only, standard mattress, and V/E mattress) for the first 10 seconds. The motion cube recorded data at 180 Hz. The Z-axis is deemed to be the most relevant to the motions in question, as it is associated with heave.

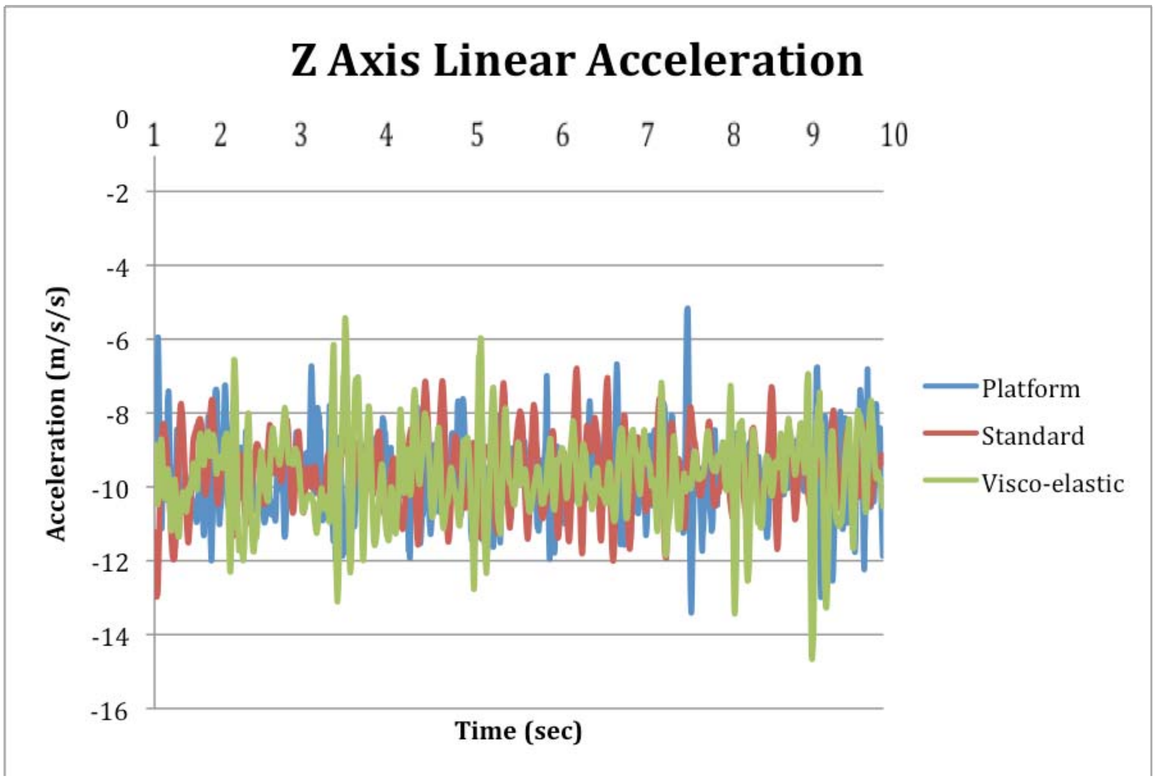

Figure 50. Z Axis Linear Acceleration

H. PREDICTED EFFECTIVENESS

When the data from the Actiware program was imported into FAST, very little variation was found between mattress types or between participants. Highly significant

differences were found between motion and stationary conditions. Figures 51 and 52 are examples of the data, but are consistent with the results across participants.

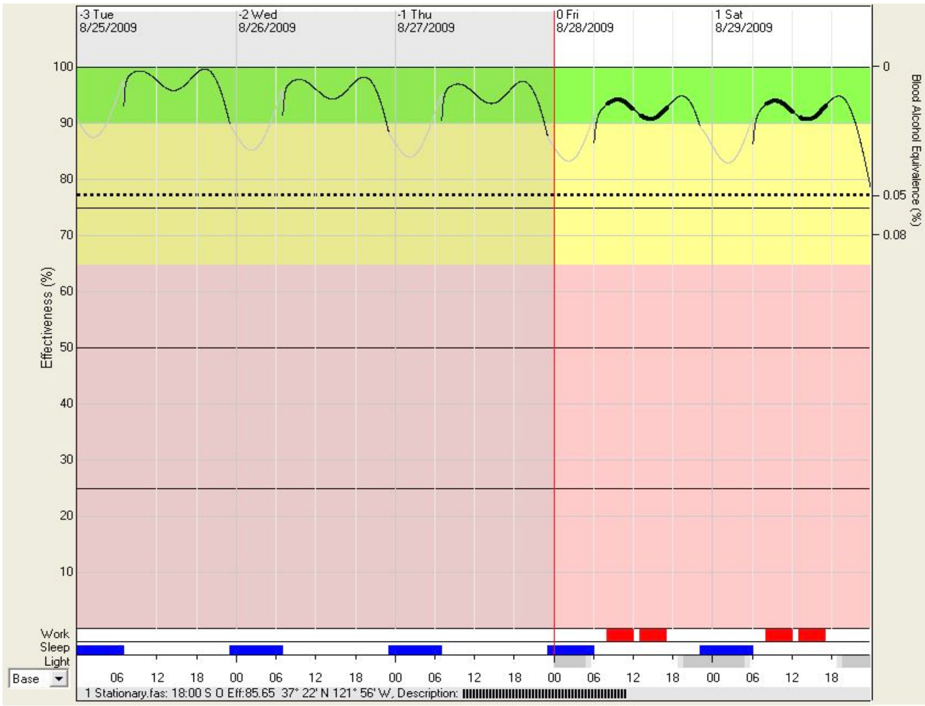

Figure 51. Stationary Predicted Effectiveness

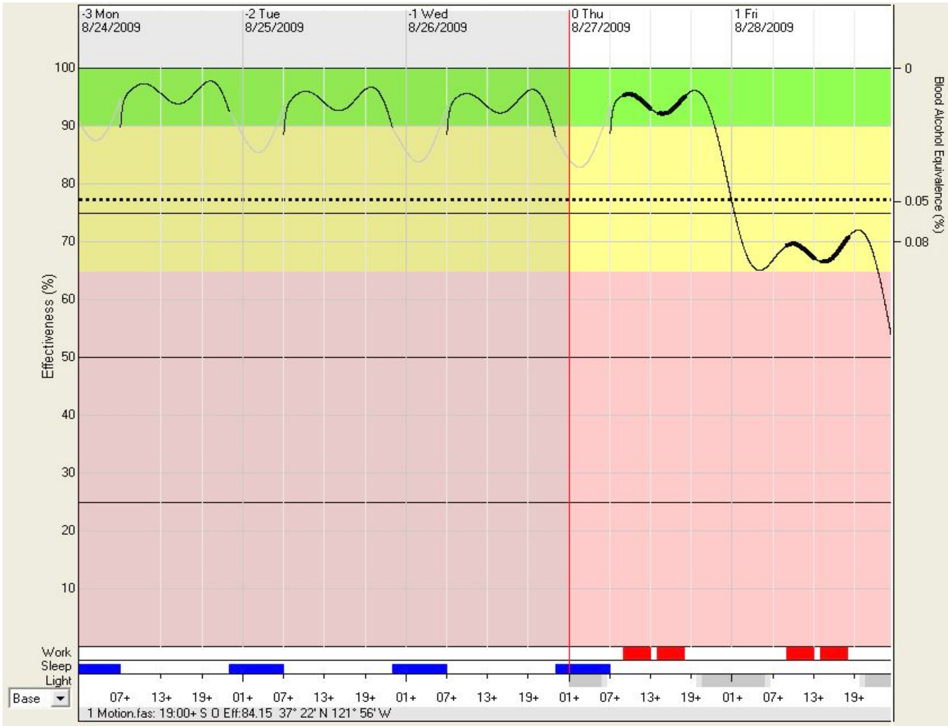

Figure 52. Motion Predicted Effectiveness

In the stationary condition, predicted effectiveness falls to around 80 percent, which is the equivalent of just under a .05 percent blood alcohol content. In the motion condition, predicted effectiveness falls to 55 percent, the equivalent of well over a .08 percent blood alcohol content, which is significantly above the legal blood alcohol equivalent.

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V. DISCUSSION AND RECOMMENDATIONS

A. MOTION AND SLEEP EFFICIENCY

Research question one asked if motion has any effect on sleep efficiency. The results indicate that there is a significant difference in sleep effectiveness between the two motion conditions. Therefore, the null hypothesis is rejected. The actigraphy data indicate a significant difference in sleep efficiency in the two motion conditions although the survey results did not completely support this conclusion.

B. MATTRESS TYPE AND SLEEP EFFICIENCY

Research question two asked if there is a difference in sleep efficiency between the standard Navy rack mattress and the visco-elastic foam mattress. In this case, we fail to reject the null and conclude that there is no significant difference between the two mattress types. This conclusion is supported by both the actigraphy data, and the survey results.

C. VIBRATION

Research question three asked if there is a significant difference in the amount of shock and vibration transmitted through the two mattress types. In this case, we can only provisionally reject the null hypothesis. The analysis is based on survey data, and on makeshift tests using the WAMs and motion cube. However, when looking at the participant-by-participant responses, one sees that those who slept on the V/E mattress did report that they felt less vibration that those who slept on the standard mattress. While the results are not statistically significant, they suggest that a larger sample size might produce significant results. The data gathered from the test using the WAMs indicates that the V/E mattress does reduce the motion activity count that was transmitted from the machine to the participant. Further testing is required in order to determine if there are differences in the amount of shock and vibration transmitted through the two mattress types.

The acceleration data from the motion cube shows very little variation in each of the three conditions (platform only, standard mattress, and V/E mattress) in the three linear axes (X, Y, and Z). Additionally, there is no conclusive evidence of differences in acceleration, in terms of pitch and roll, across conditions. More research is needed on the transmissibility of the mattress types, and how they affect sleep.

D. PREDICTED EFFECTIVENESS

The results from the FAST program were quite clear. There was a significant difference in predicted effectiveness between the motion and stationary conditions. Predicted effectiveness was higher, above 80 percent, in the stationary condition than in the motion condition. In contrast, the motion condition led to a steep drop in predicted effectiveness to about 50 percent. What this means is that after sleeping in the motion condition, on either mattress type, a participant would have a seriously degraded predicted effectiveness, equivalent to that of a person who is legally drunk, clearly impacting that person's ability to perform even the most basic tasks in any environment. On a ship, a person in this condition would pose a grave danger to both the ship and its mission.

E. CAVEATS

While the researchers took extensive steps to minimize potential confounding variables in this study, there were several issues that were unavoidable. These issues are recounted and explained in this section.

1. Sample Size

The sample size for this study was relatively small (n=12). As a result, the researchers had low power for statistical tests in several areas of the analysis. Much of the results suggest that, had the sample size been larger, significance may have been obtained in these areas. The reason for the small sample size revolved around the nature of the data collection. The experiment required a great deal of time from the participants, including wearing the WAM and keeping the activity log for a full week, plus the two nights in the

laboratory. While in the laboratory, the participants often experienced poor sleep, especially on the motion platform. This affected participant performance when they resumed their normal routines.

2. Participant Makeup

The demographic makeup of the participants was also a matter of some concern. Ages ranged from 25 to 43, which is clearly a large spread. With such a small sample size, this variance in age may well have skewed the data, as people of different ages tend to have different sleep patterns. On the positive side, the age range does cover most of the ages one would find on a typical Navy warship.

In terms of gender, there was only one female in the sample. Since there can be differences in the sleep patterns of males and females, this also may have skewed the results. However, we decided to include her to maximize the number of participants.

3. Laboratory Conditions

While the researchers were able to control most of the conditions in the laboratory, there was some variation in terms of temperature. The ability to control the air conditioning system was limited; temperatures varied between 65 and 75 degrees throughout the course of each night. On a typical Navy warship, the temperature in the berthing compartments does remain fairly constant; participants were probably used to sleeping in different temperatures at home. Therefore, if the temperatures experienced in the lab were different from the baseline conditions, sleep efficiency could have been affected.

4. Machine Limitations

While the motion machine was an effective simulator for this initial study, it was not capable of replicating the motions of the USS Swift (HSV-2). In particular, heave was limited to a total displacement of only four inches. The actual motions of the HSV-2 exceeded these limits by a substantial amount. Although the motion machine was not able to simulate the full HSV-2 motion, it was sufficient for this initial analysis of motion effects and mattress type on sleep.

F. DISCUSSION

When the researchers began the pilot study that preceded this thesis, the goal was to assess the feasibility of the method. Based on a review of the relevant literature, there had never been a similar study. In this respect, the pilot study was a success, since it enabled the current study to proceed. While not a specifically stated goal of this thesis, the researchers hoped to further support the pilot study results. In this effort we were successful, regardless of the statistical results. Hopefully, armed with the knowledge and experience that this study yielded, future research will be conducted using a similar methodology.

Despite the somewhat mixed results of this study, there are implications when one considers the literature that was reviewed in Chapter II. Regardless of how ships of the future are designed, whether they are mono-hulled, catamarans or trimarans, the Navy will be reducing its manning. With the introduction of new technologies, such as the Voyage Management System (VMS), the need for personnel will decrease, at least in the Navy's eyes. According to the Northrop Grumman Products Web site (2009), the VMS is a digital plotting tool that will replace the paper charts that are currently in use. Paper charts require a number of sailors to perform various functions during restricted maneuvering situations, while VMS does not. In addition, there are entire rates that either have already, or will soon, disappear. It was not that long ago that there was a signalman rating in the Navy. Today, that rating is only a memory. From a financial point of view, the Navy's reasons for reducing manning make sense. People cost a great deal of money to recruit, train, and maintain, and, as was cited in the literature review, the Navy wants to have its reduced manning infrastructure in place when the ships of the future arrive. The implications of this decision, however, are serious. This thesis cited a number of examples in which reduced manning, and the resulting fatigue, caused expensive accidents. Yet, it seems clear that the Navy is not going to shift course and increase manning. This only underscores the importance of research on sleep efficiency.

The results of this thesis indicate that motion has a definite effect on sleep efficiency, as well as on predicted effectiveness, according to the survey and empirical data. While it is certainly possible that some Sailors may be able to adapt to these

degraded sleep conditions over time, those conditions are by no means optimal. Therefore, steps should be taken to mitigate these negative effects, and the changes should be implemented on the ships of today, rather than waiting for future ship classes to enter service. Since the Navy intends to have its reduced manning infrastructure in place before vessels like the LCS and JHSV arrive, it makes sense that the methods for improving sleep efficiency should also be in place ahead of time.

It might be more reasonable for the Navy to simply increase the size of future crews. Larger crews may cost more, but they also provide redundancy, and allow for a higher level of specialization. It does not make sense for a quartermaster, for example, to have to learn the job of the Boatswain's Mate of the Watch (BMOW). To do so might result in reduced skills in both areas, not to mention divided attention during critical operations. It could be more cost-effective to pay for larger crews than to pay to repair a ship that has run aground. Monetary concerns aside, incidents such as groundings and collisions may also have a high price in terms of lives and damaged careers.

The literature review also examined the NSWW, and found that it is often violated. The NSWW does not account for many of the realities of life on a surface ship in today's Navy. Between drills, watch, divisional and collateral duties, there is insufficient time left for sleep. While there may be little or nothing that can be done about operational requirements, one solution would be to maintain adequate crew sizes. In addition, the Navy should consider the possibility of adopting new sleeping surfaces. The data produced by this study is inconclusive in terms of the benefits of the V/E mattress, but further research is warranted.

The most important results found in this thesis deal with the effect of motion on sleep efficiency and predicted effectiveness. While it is possible that Sailors would be able to adapt to the motions during sleep, it is also possible that the effects may worsen over time. To address this, the Navy should continue the research begun in this study in terms of sleeping surface. It should also consider the implications of shiftwork as it relates to watch schedules. The standard watch rotation on a typical surface ship is five hours on/10 hours off, which constitutes a three-section watch rotation. While some ships employ a four-section rotation, this does not seem to be the norm. Even in the case of a

four-section watch rotation, intense operations would pose a limiting factor. Again, watch rotation may not be subject to change, but steps can be taken to insure that Sailors can achieve more and higher quality sleep.

While the methods employed by this study are not ideal, the results at least suggest that the vibrations caused by the motions of catamaran vessels will impact sleep efficiency, and as a consequence, predicted effectiveness.

G. RECOMMENDATIONS FOR FUTURE RESEARCH

This study employed a number of methods to assess the effects of shipboard motion on sleep efficiency. In some respects, these methods were effective. At the very least, the use of a laboratory to determine the effects of motion was found to be feasible. However, in terms of vibration, the researchers did not have access to the ideal equipment in terms of either motion generation or measurement. Therefore, future research should be conducted with appropriate tools if they can be identified.

A future study should also use data gathered from high-speed vessels under a number of conditions, including varying sea states and speeds. This study was limited to input data from one ship, and a limited displacement motion platform. Such a study should also include a much larger sample size. A sample composed of officers and enlisted personnel would also be useful, as the duties and responsibilities of these two groups are varied.

Finally, as was mentioned in the Caveats section, the motion machine was limited in its ability to replicate the motions of the HSV-2. A future study should explore the use of a higher-quality machine, capable of simulating heave, pitch and roll to a much greater extent.

In conclusion, this study provided data to benefit the Navy. While additional research is required to fully explore the recommendations discussed in this study, it is clear that such research is warranted, and at the very least, the methodology has been proven sound. The most valuable asset in the Navy is its people. Every measure available to ensure that they are effective at their given tasks is essential. While reducing costs is

important, so is ensuring crew safety and mission accomplishment. The researchers are confident that costs can be controlled by balancing the benefits of personnel reduction and accident avoidance. Therefore, the research begun in this study must continue so that feasible solutions can be developed to ensure maximum sleep efficiency and Sailor effectiveness.

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APPENDIX A. ACTIGRAPHY DATA

The following figures are the baseline and laboratory actigraphy data for all participants.

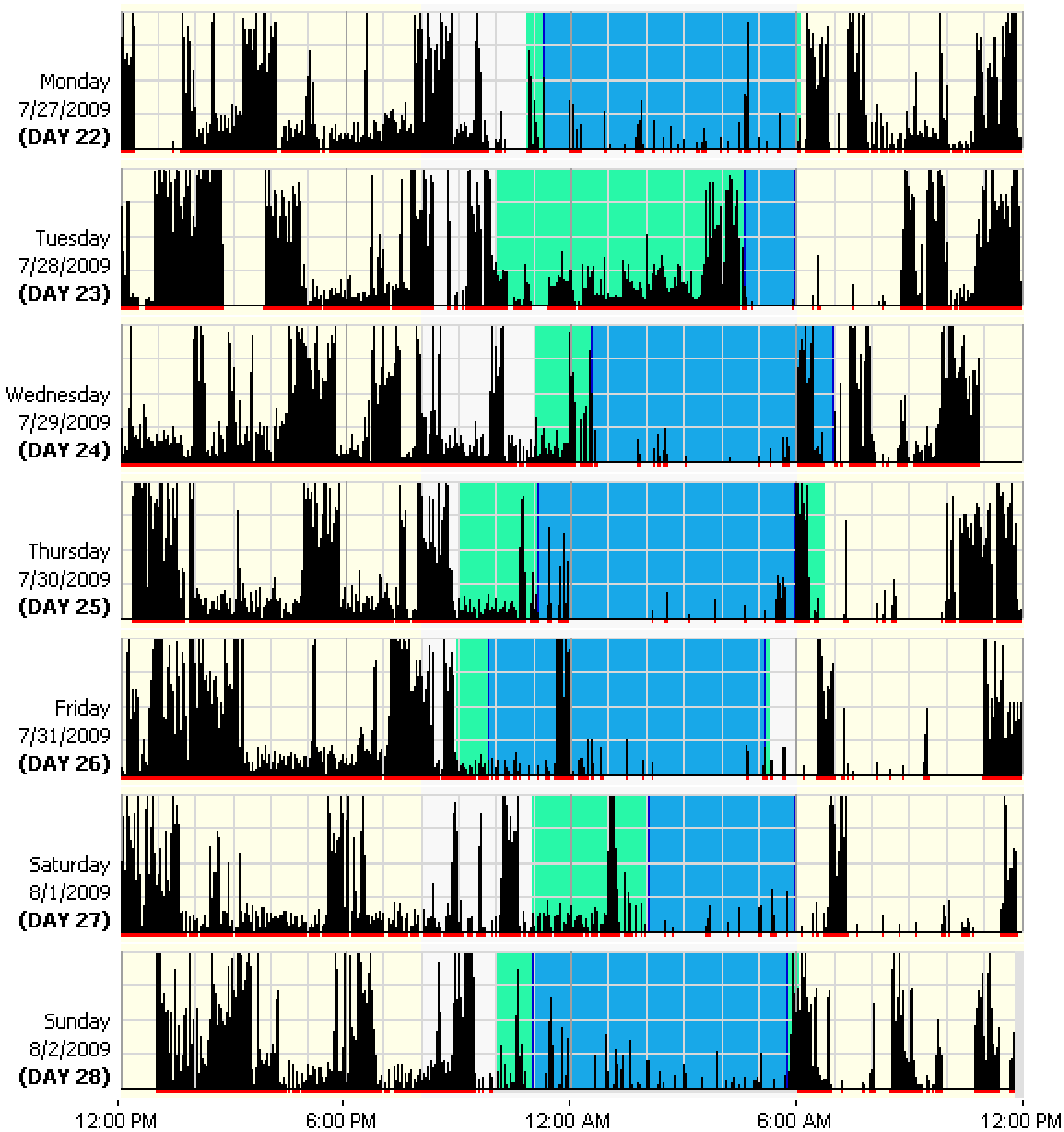


Figure A1. Participant One Baseline

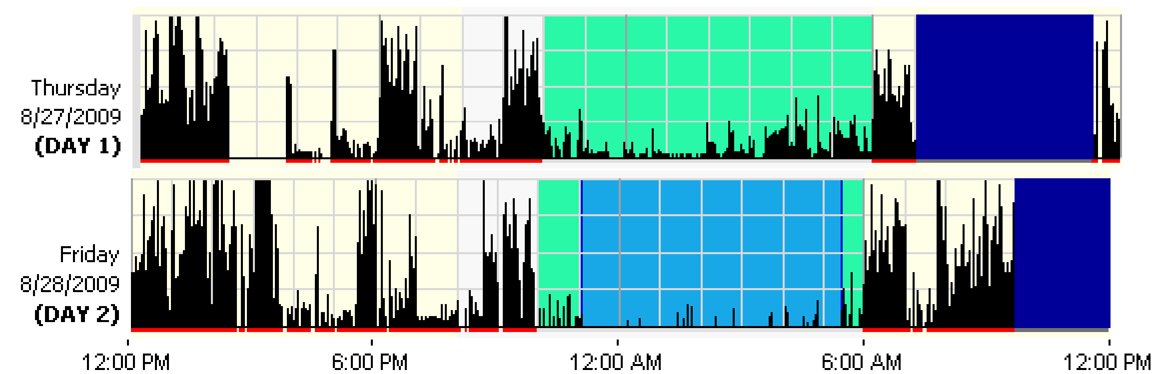
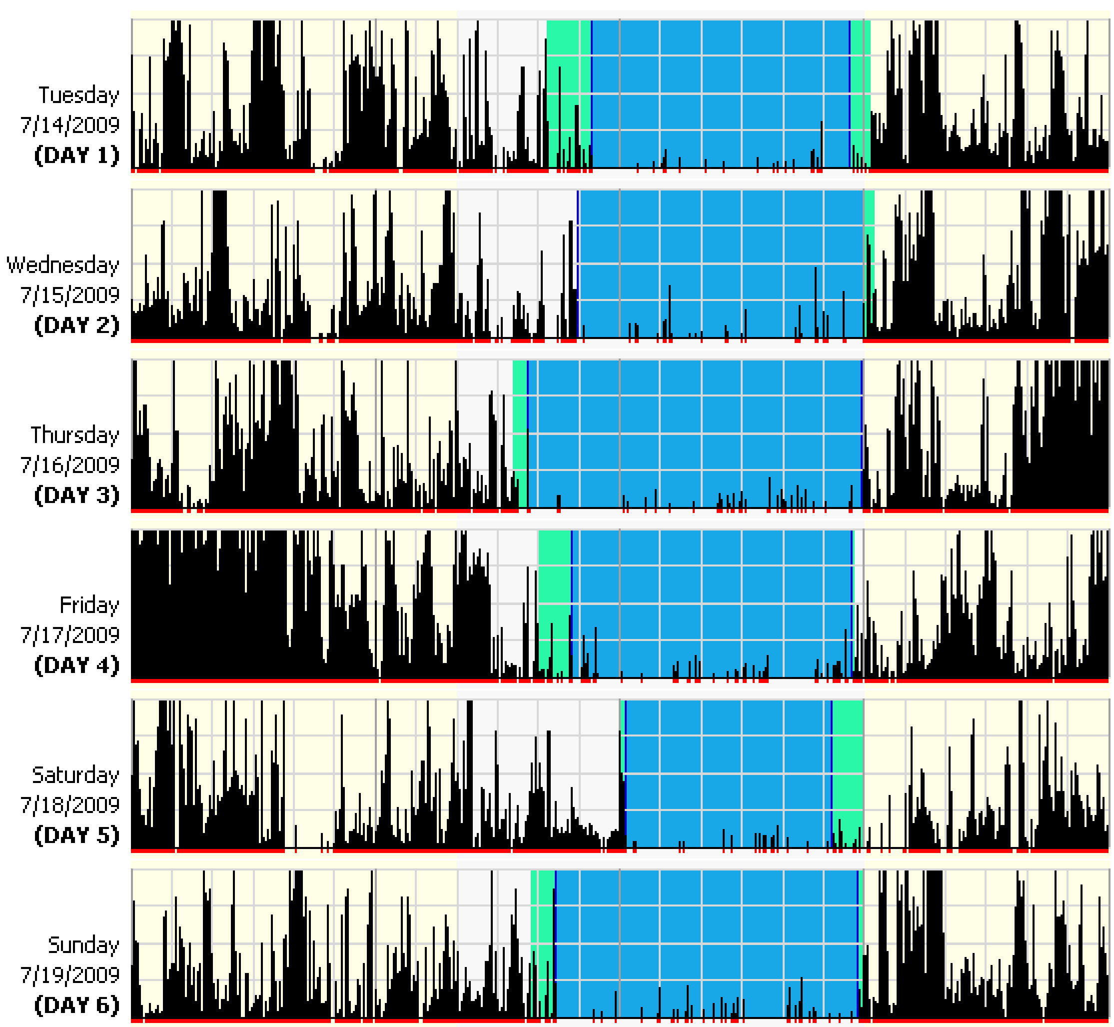


Figure A2. Participant One Laboratory



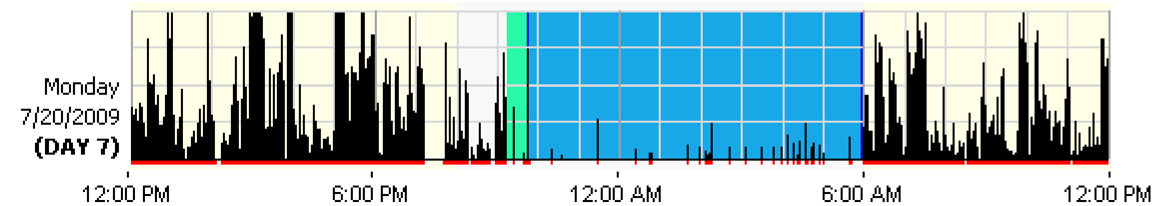


Figure A3. Participant Two Baseline

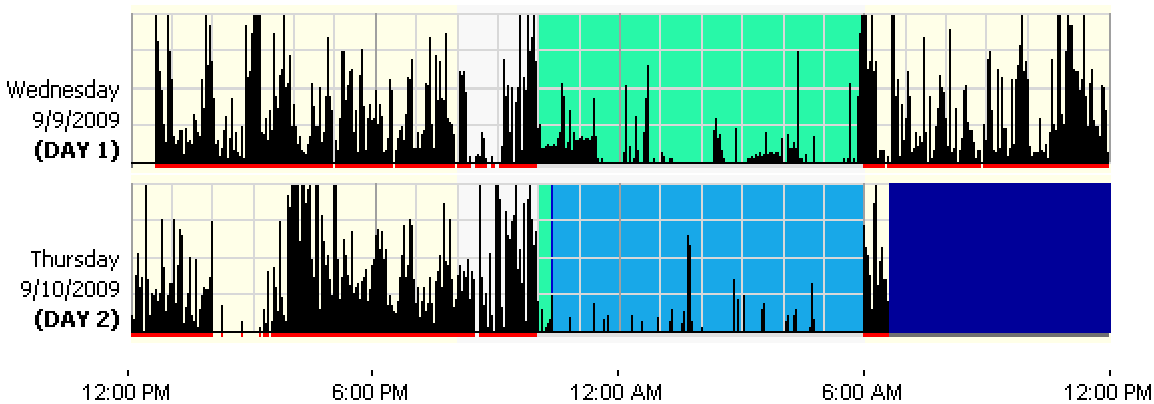
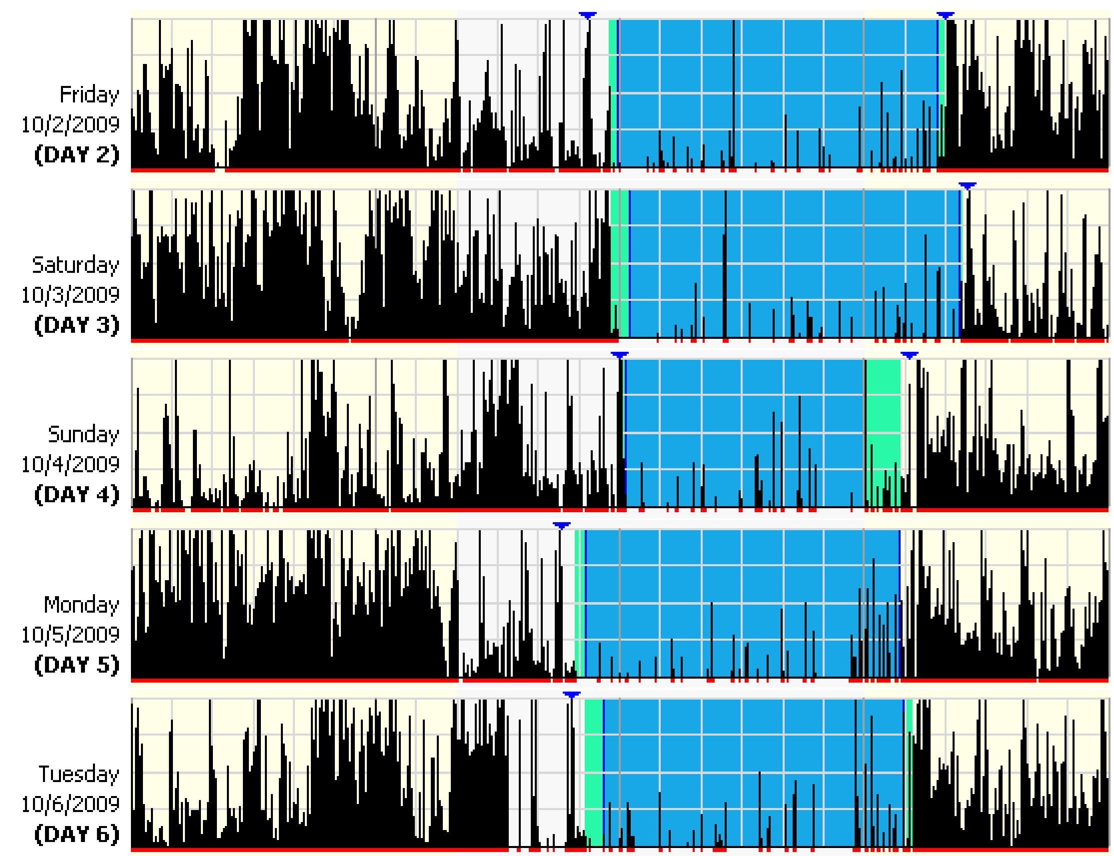


Figure A4. Participant Two Laboratory



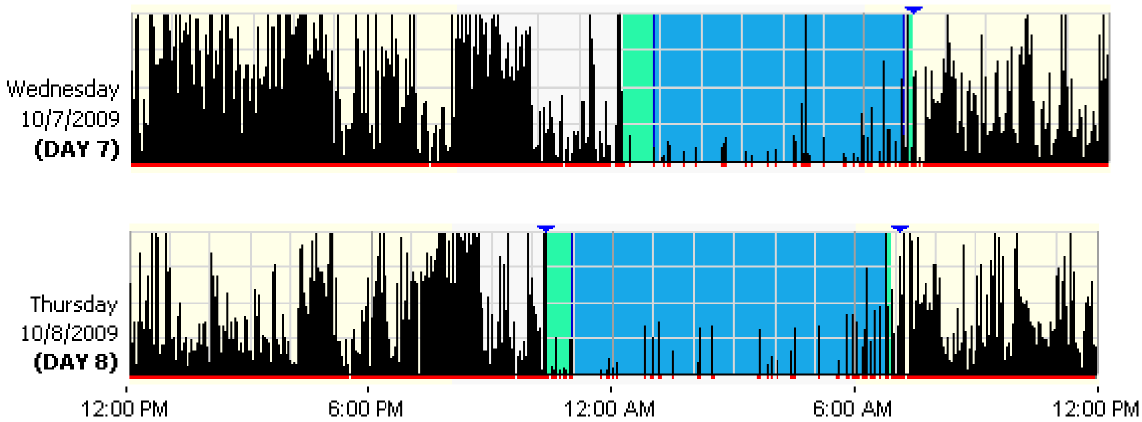


Figure A5. Participant Three Baseline

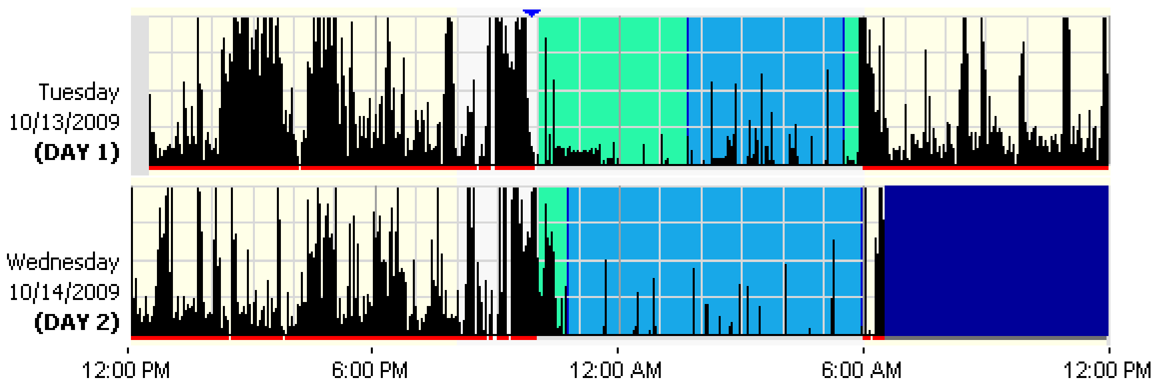
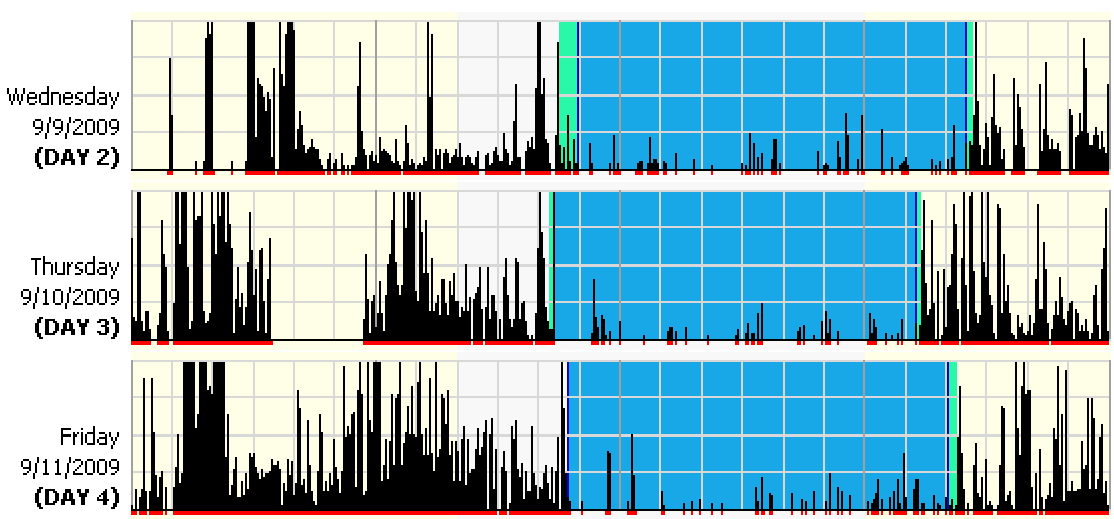


Figure A6. Participant Three Laboratory



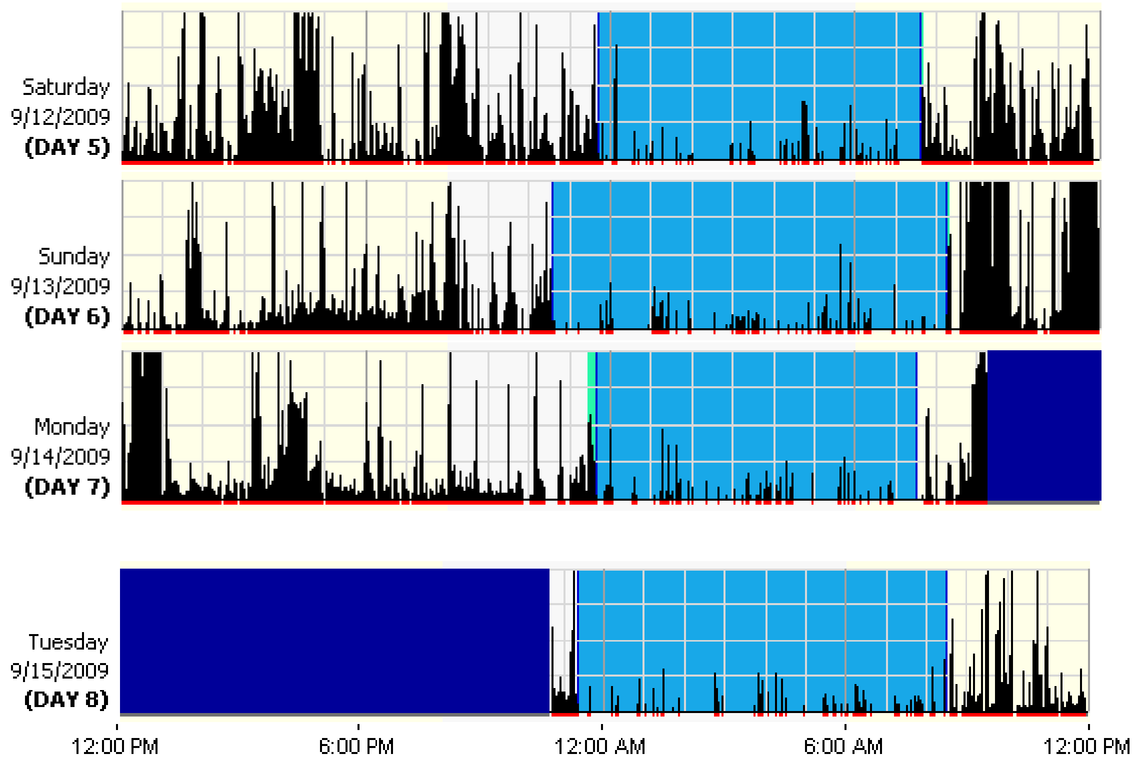


Figure A7. Participant Four Baseline

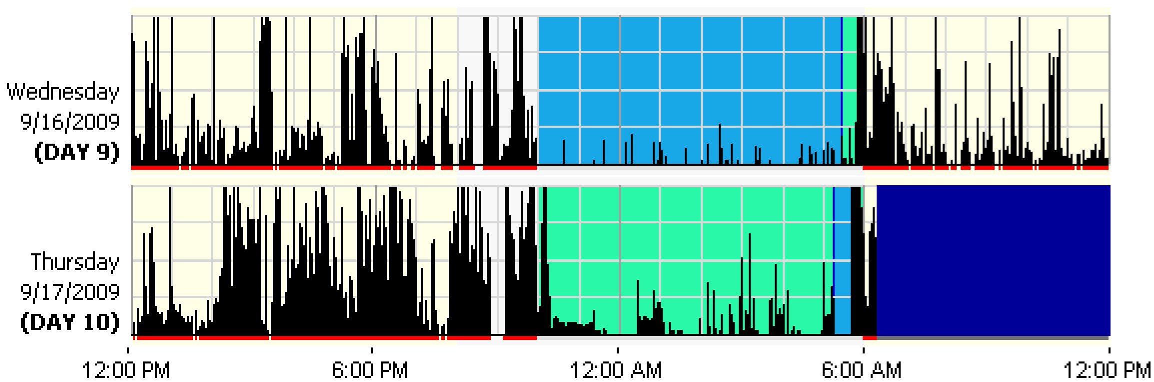


Figure A8. Participant Four Laboratory

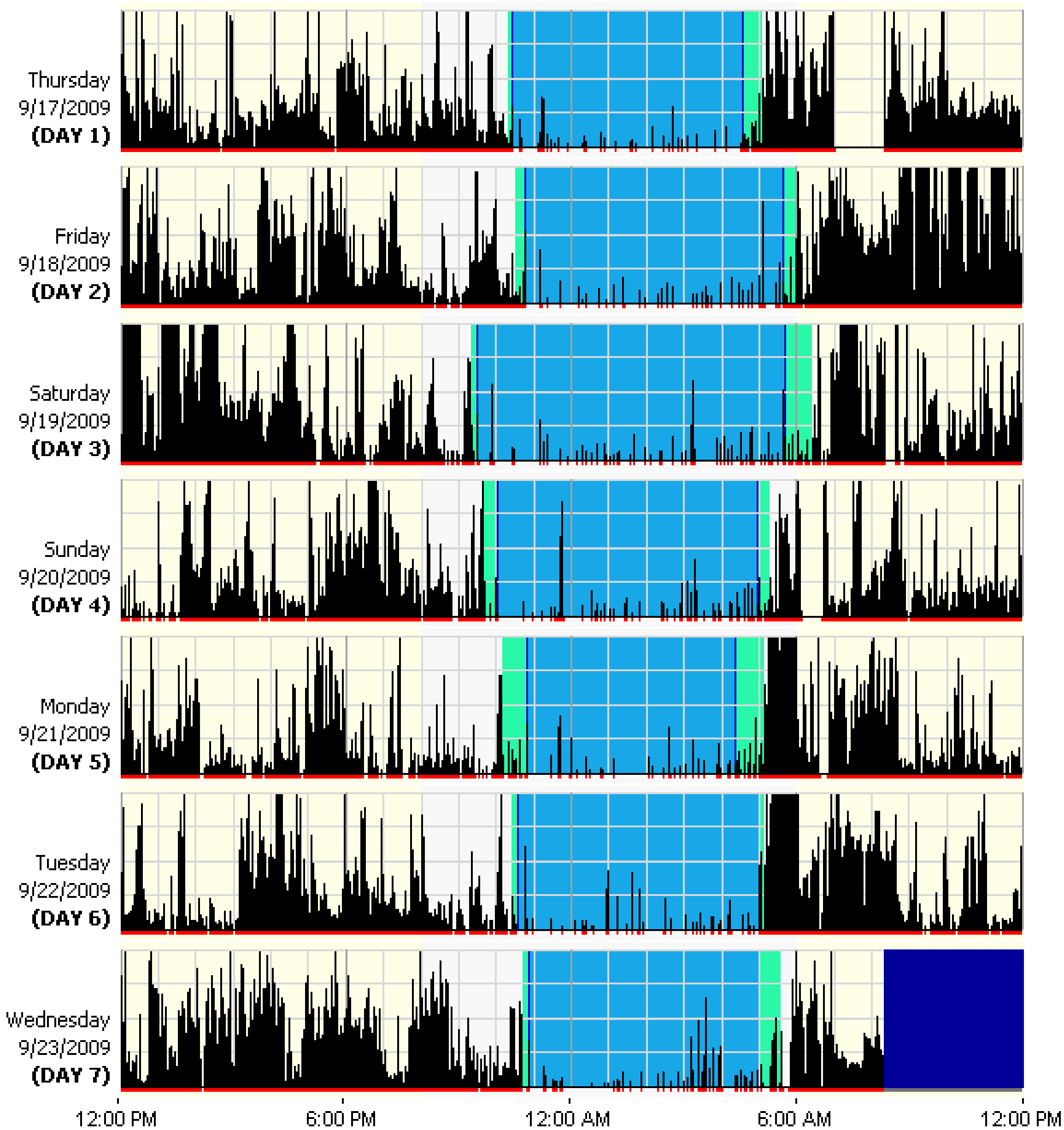


Figure A9. Participant Five Baseline

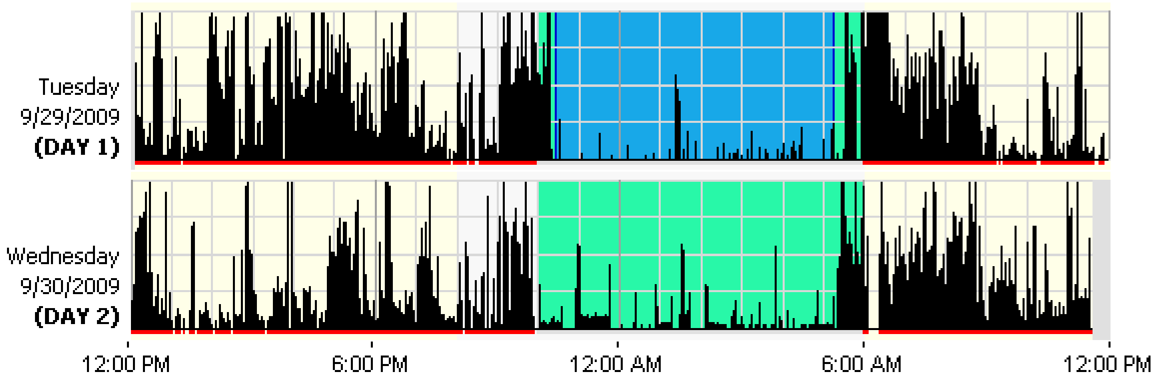
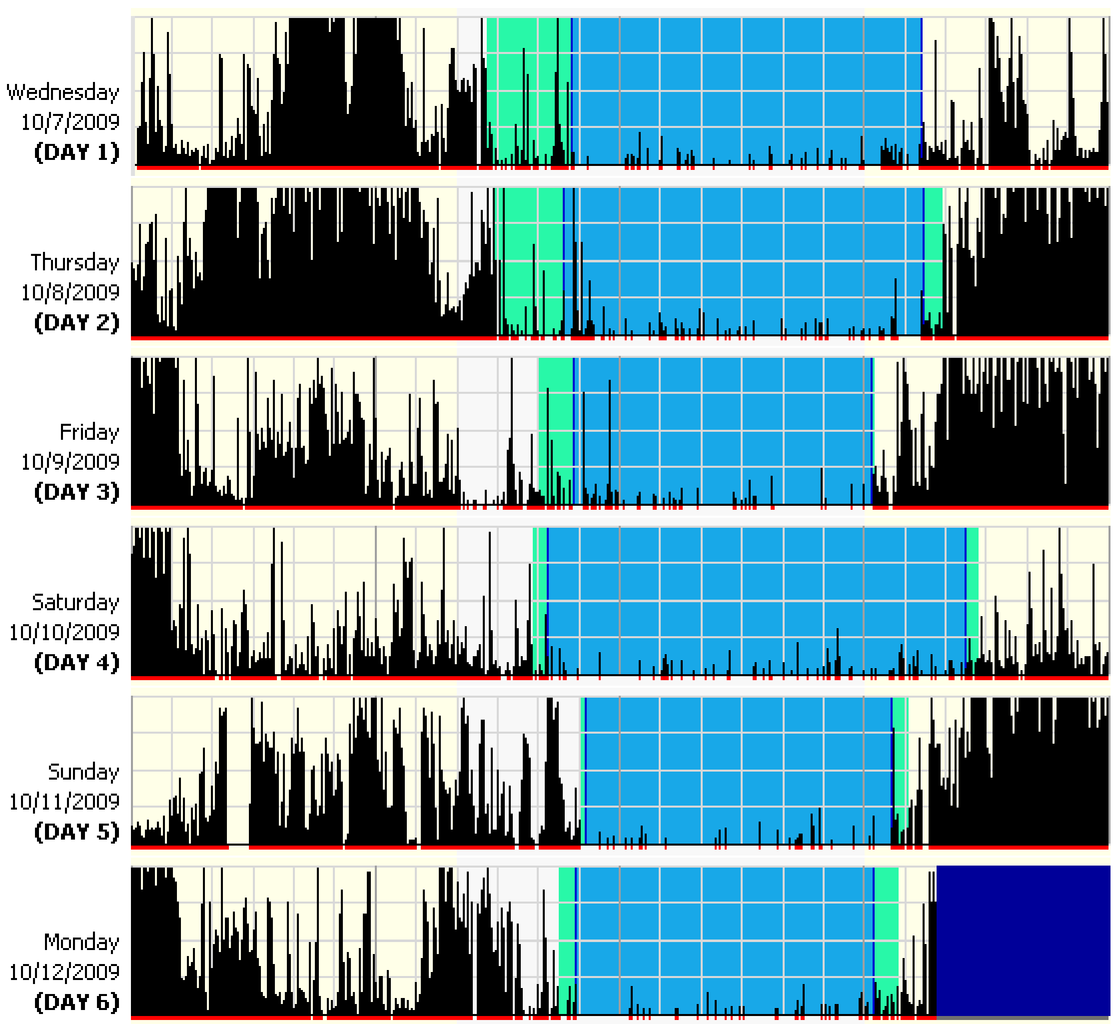


Figure A10. Participant Five Laboratory



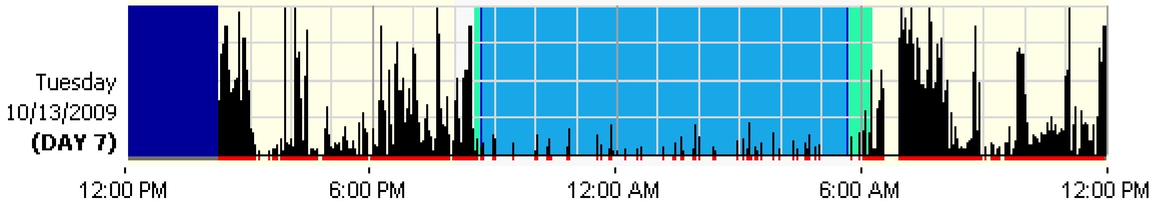


Figure A11. Participant Six Baseline

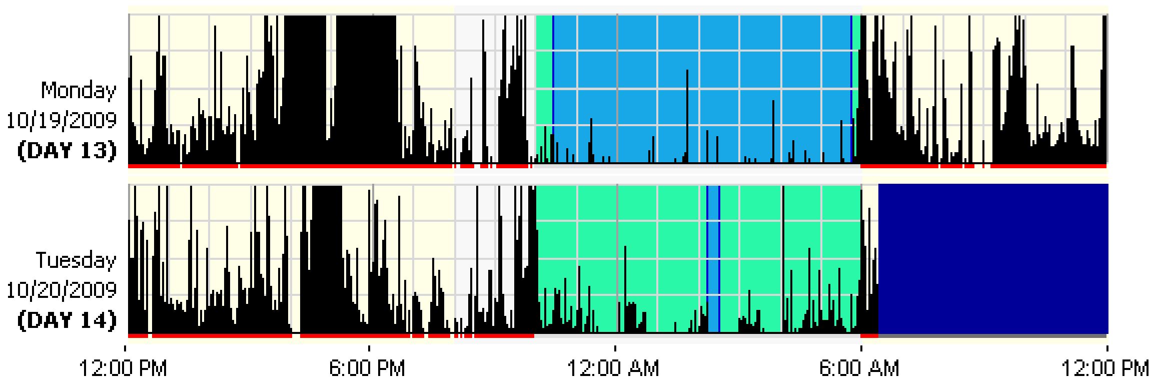
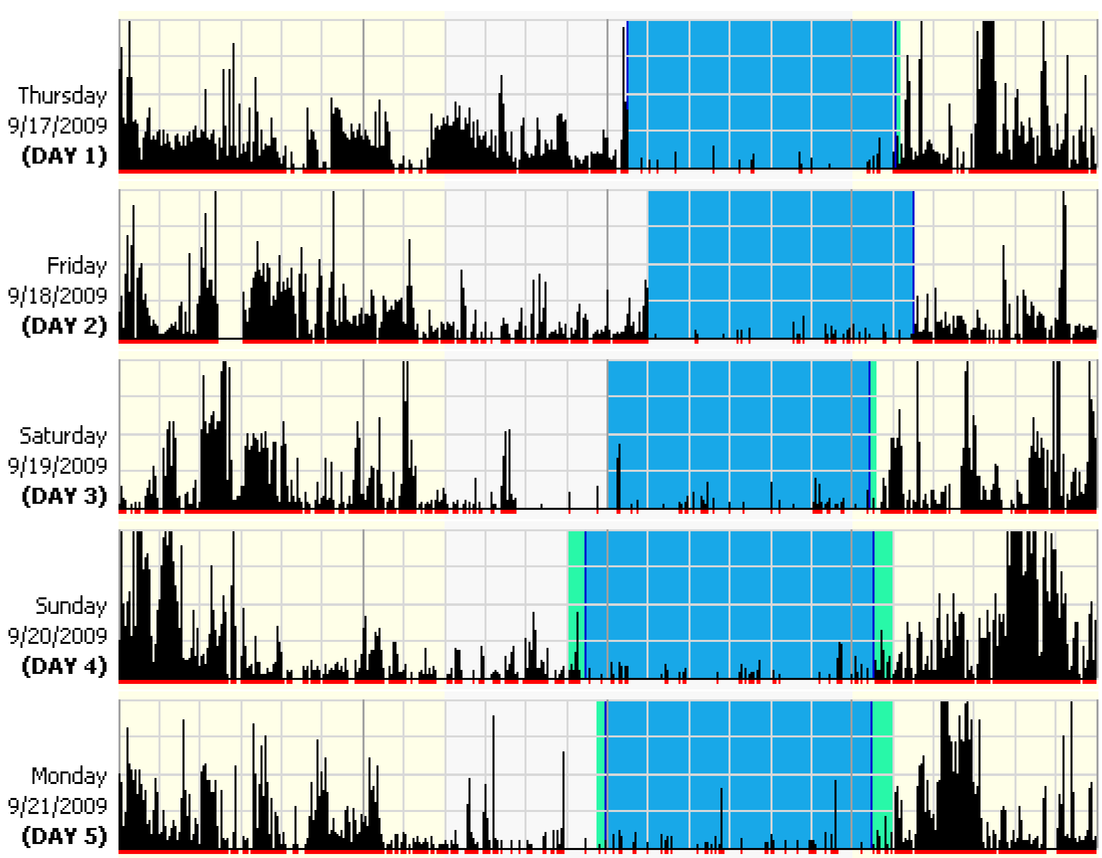


Figure A12. Participant Six Laboratory



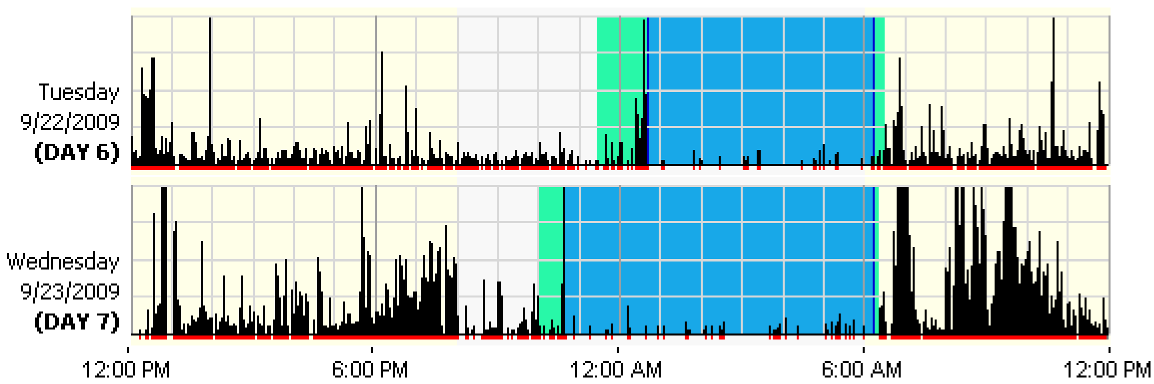


Figure A13. Participant Seven Baseline

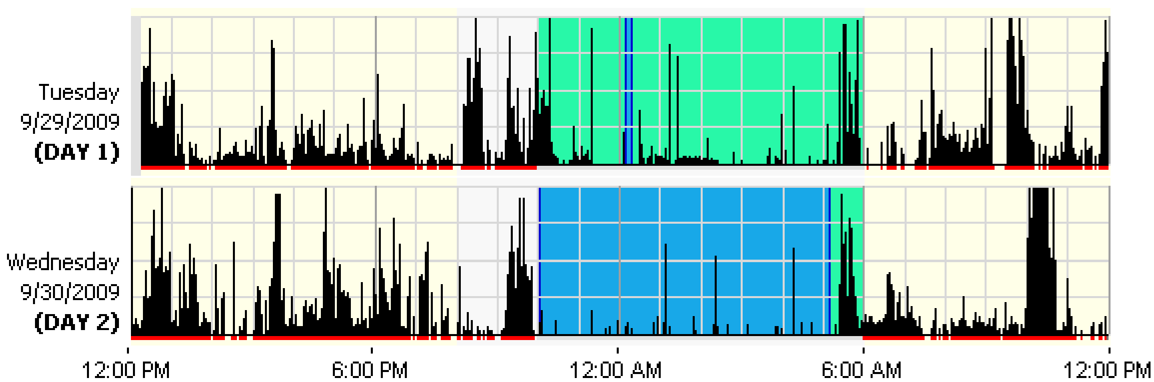
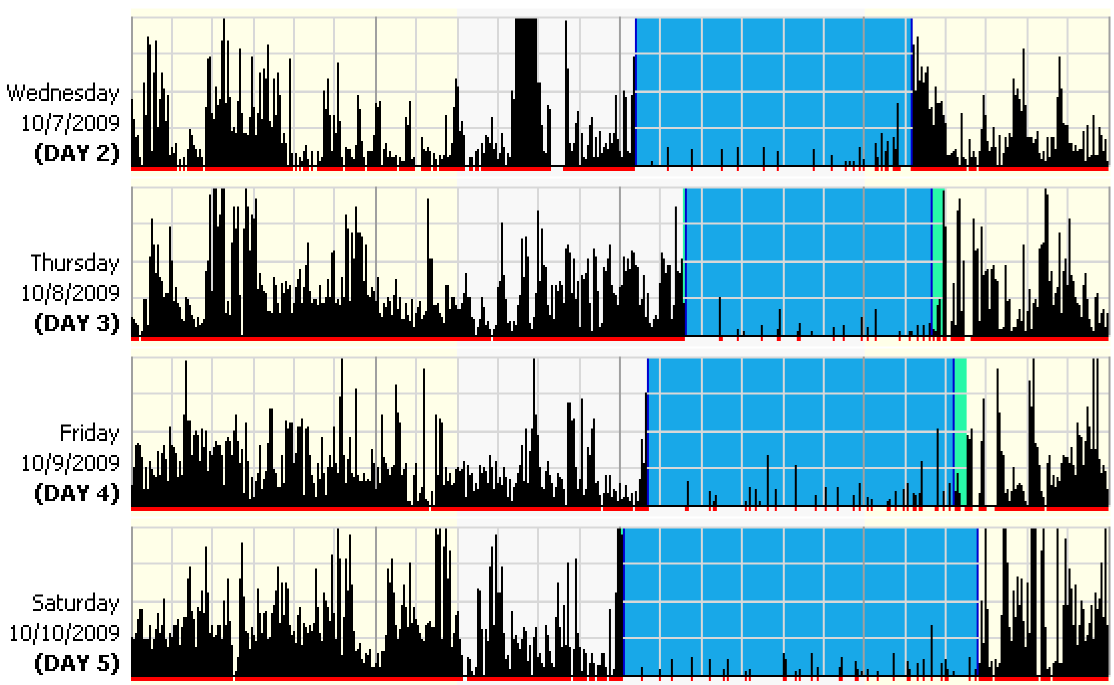


Figure A14. Participant Seven Laboratory



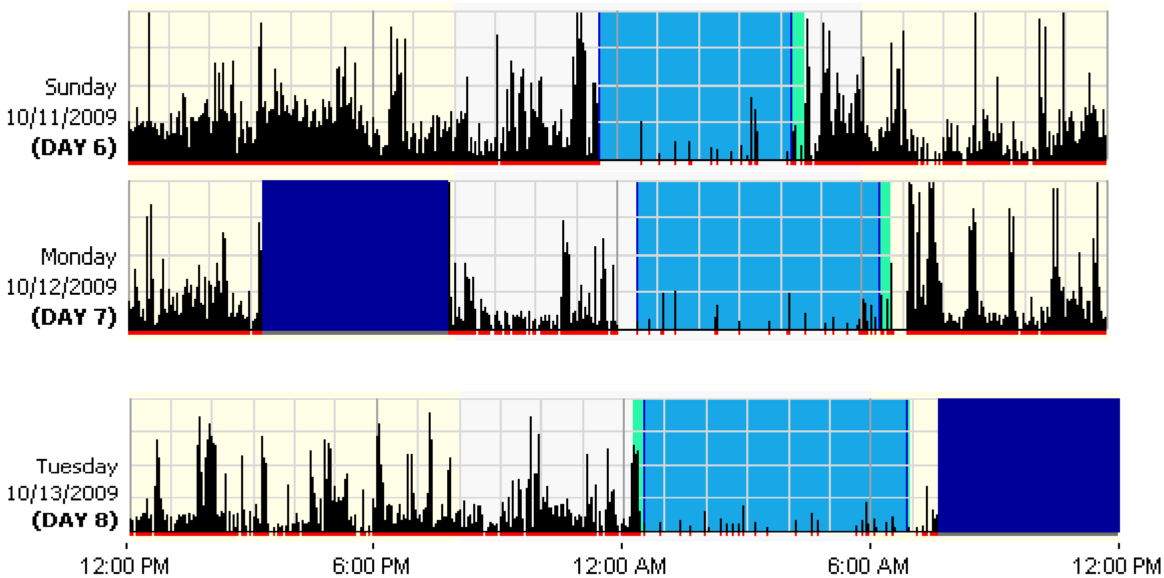


Figure A15. Participant Eight Baseline

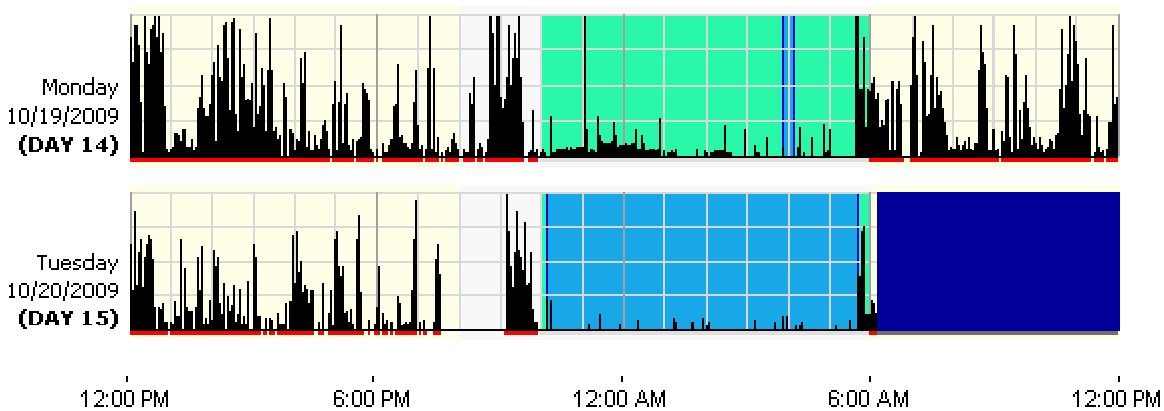
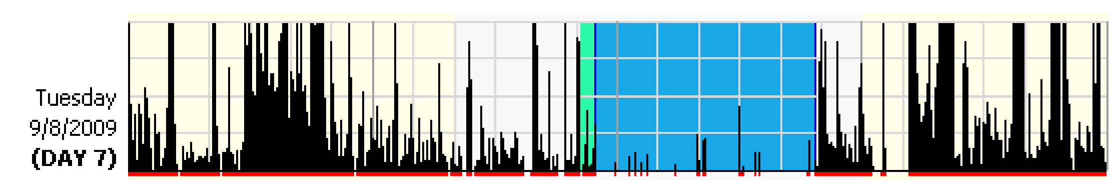


Figure A16. Participant Eight Laboratory



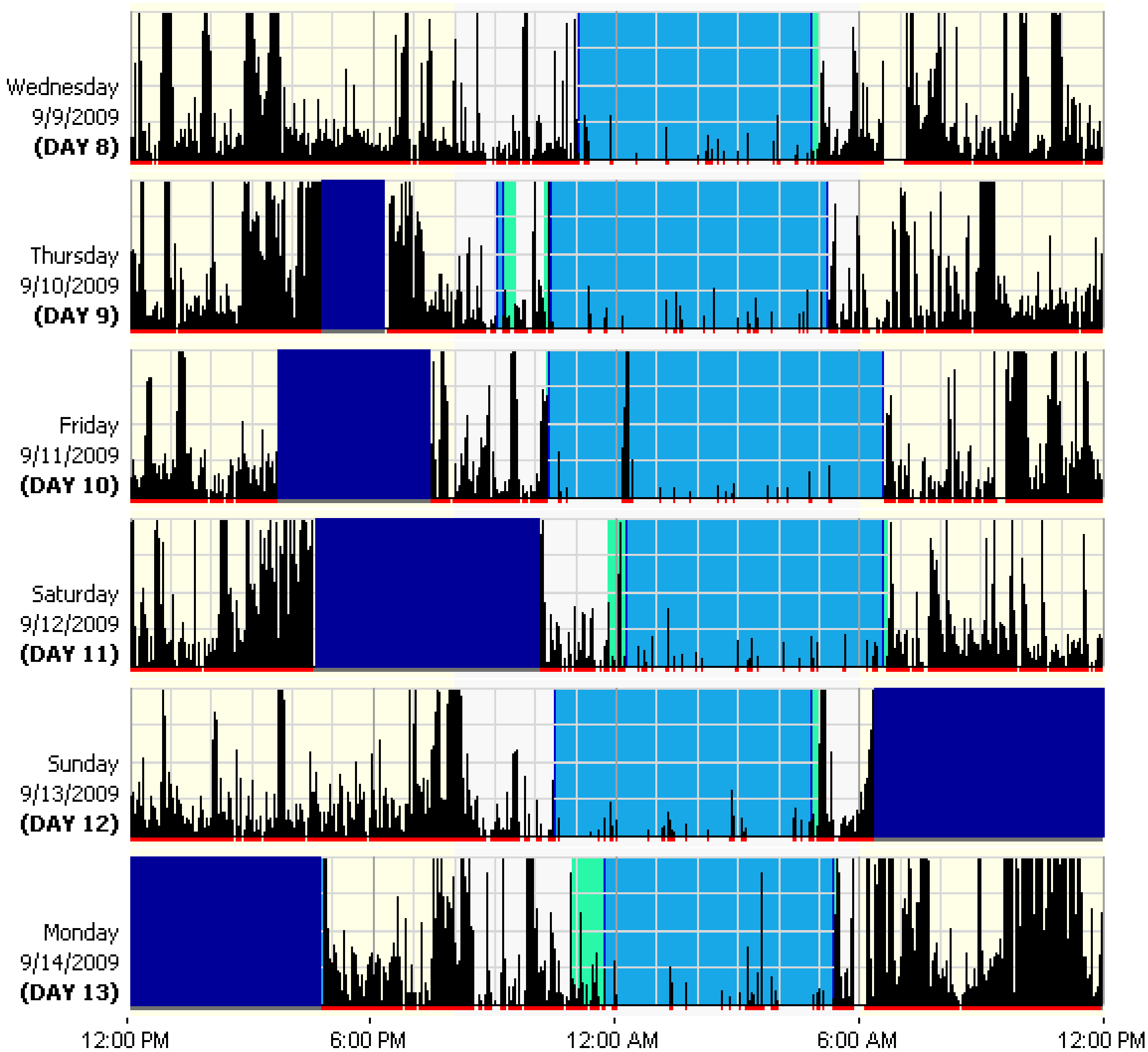


Figure A17. Participant Nine Baseline

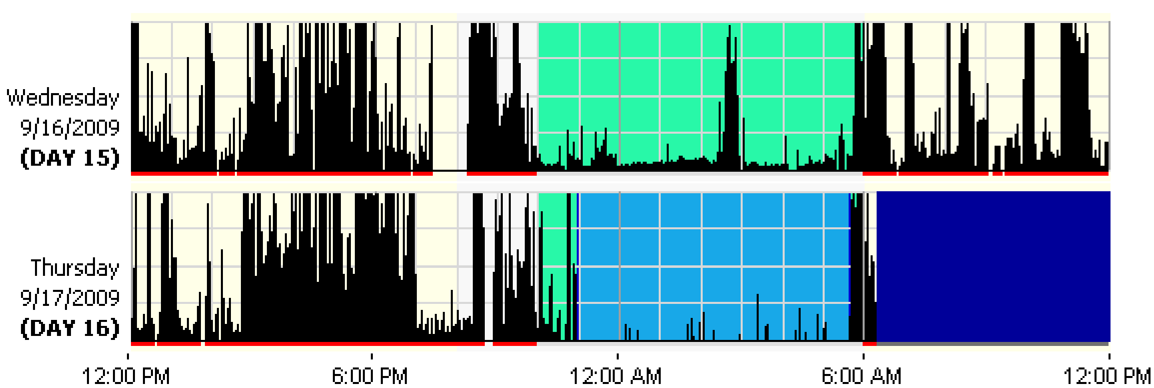


Figure A18. Participant Nine Laboratory

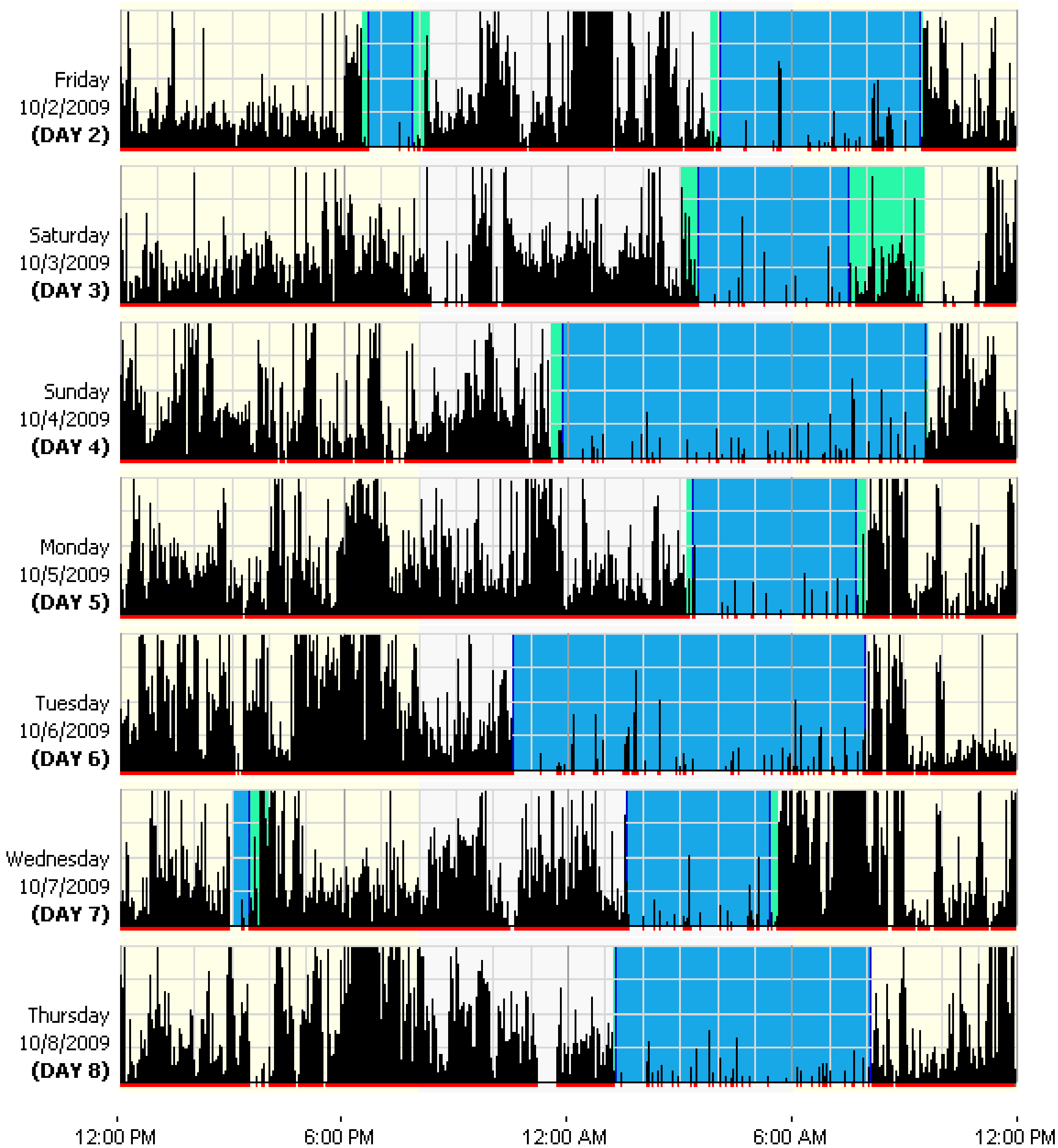


Figure A19. Participant Ten Baseline

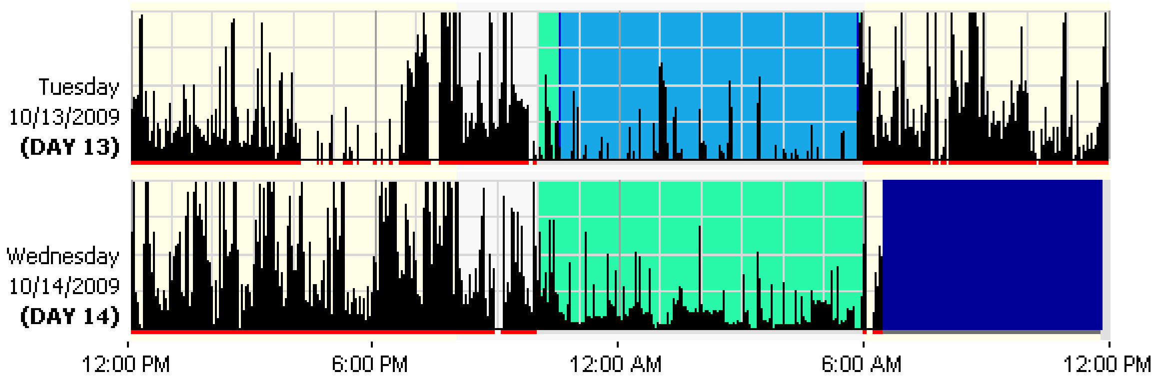
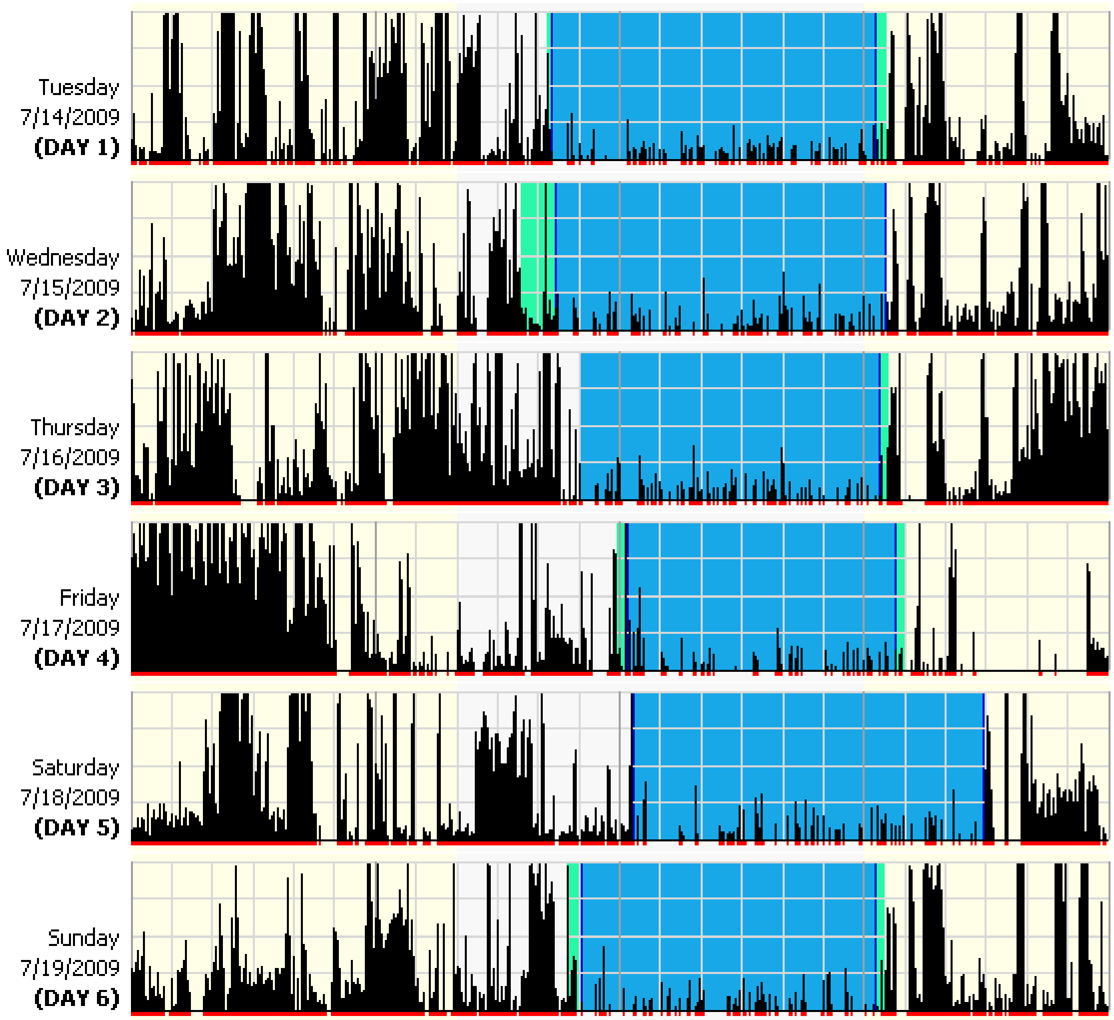


Figure A20. Participant Ten Laboratory



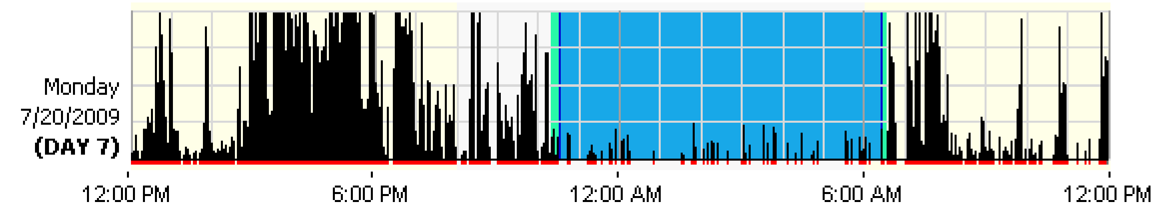


Figure A21. Participant Eleven Baseline

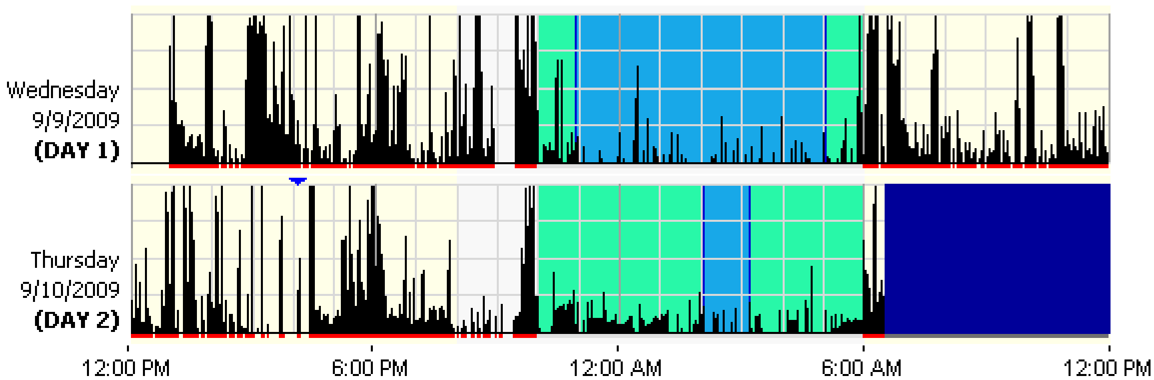
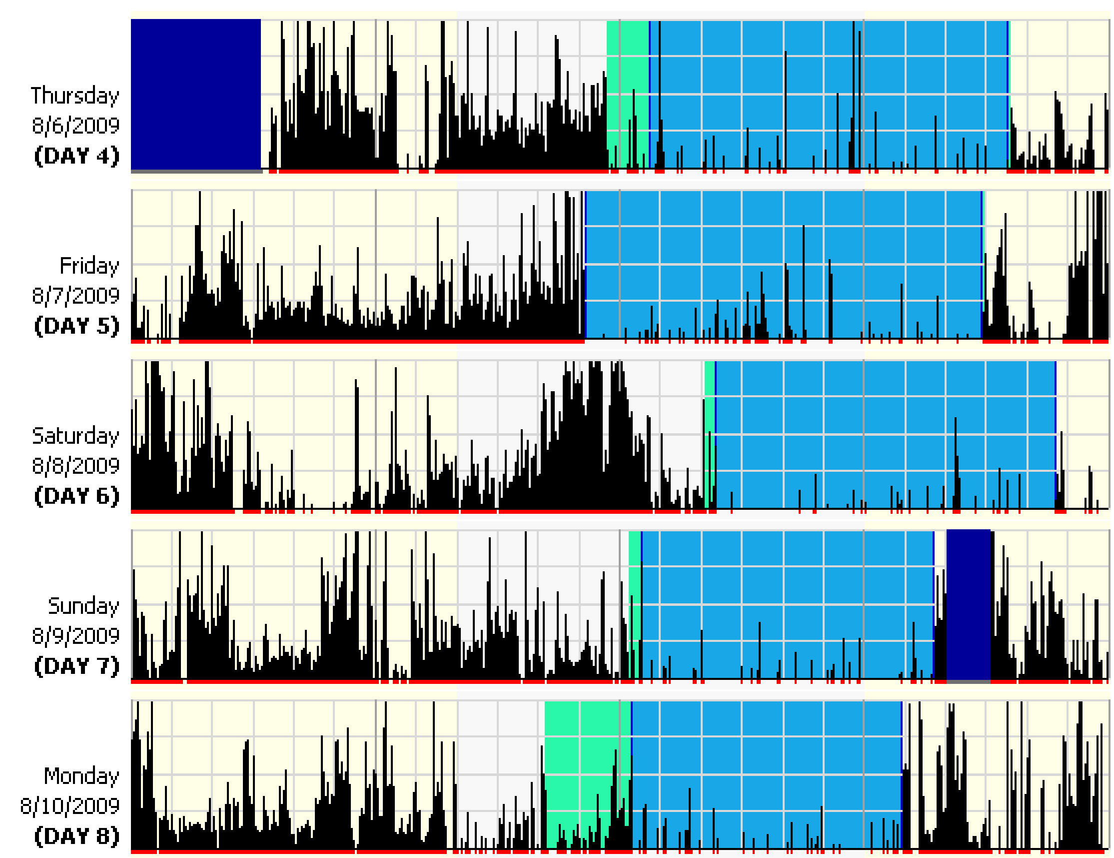


Figure A22. Participant Eleven Laboratory



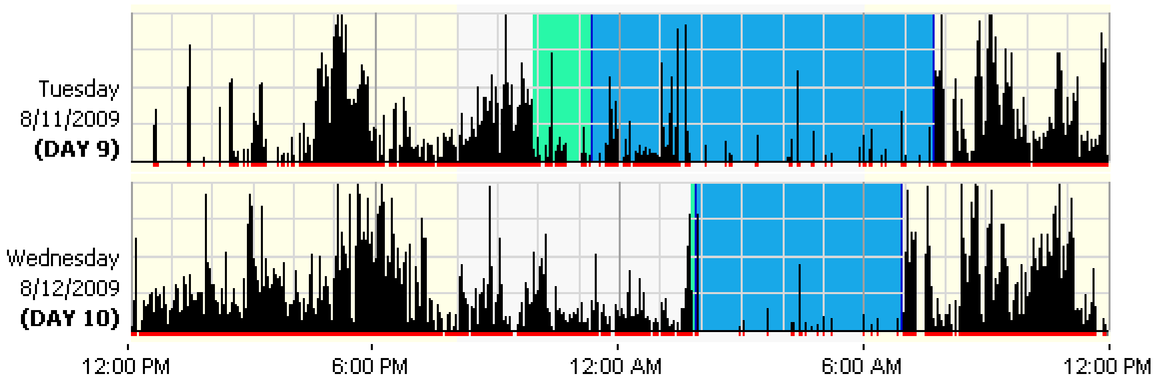


Figure A23. Participant Twelve Baseline

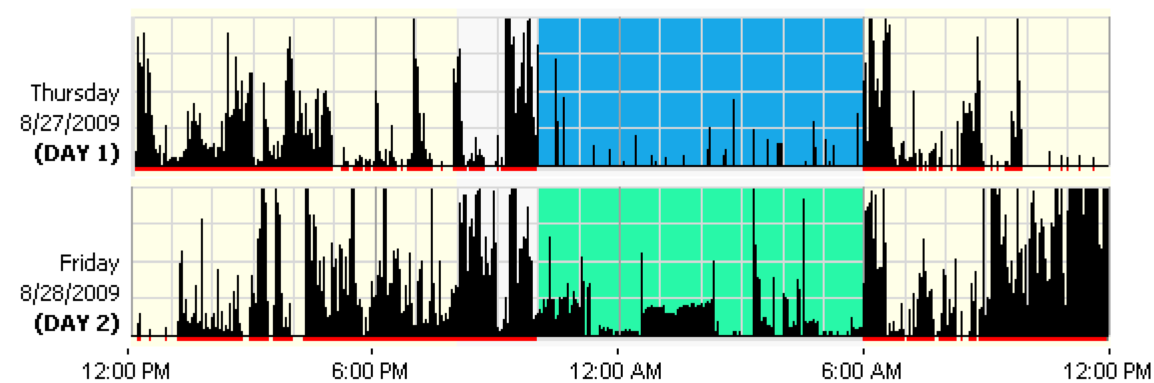


Figure A24. Participant Twelve Laboratory

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APPENDIX B. PRE-EXPERIMENT QUESTIONNAIRES

The three sections of Appendix B consist of the surveys and questionnaires that each participant was required to fill out for screening purposes.

A. MOTION HISTORY QUESTIONNAIRE

Subject Number: ________ Date: ____________

1. Approximately how many total <u>flight</u> hours do you have? ____ hours
2. How often would you say you get airsick?
   Always___ Frequently___ Sometimes___ Rarely___ Never____
3. a) How many total flight <u>simulator</u> hours? _____ Hours
   b) How often have you been in a virtual reality device? _____ Times _____ Hours
4. How much experience have you had at sea aboard ships or boats?
   Much ____ Some ____ Very Little ____ None ______
5. From your experience at sea, how often would you say you get seasick?
   Always ___ Frequently___ Sometimes___ Rarely___ Never____
6. Have you ever been motion sick under any conditions other than the ones listed so far?
   No___ Yes___ If so, under what conditions?
7. In general, how susceptible to motion sickness are you?
   Extremely__Very__Moderately__Minimally__Not at all______
8. Have you been nauseated <u>FOR ANY REASON</u> during the past eight weeks?
   No ___ Yes ___ If yes, explain
9. When you were nauseated <u>for any reason</u> (including flu, alcohol, etc.), did you vomit?

Easily ___	Only with difficulty ___	Retch and finally vomited with great difficulty ________

10. If you vomited while experiencing motion sickness, did you:
    a) Feel better and remain so?
    b) Feel better temporarily, then vomit again?
    c) Feel no better, but not vomit again?
    d) Other - specify
11. If you were in an experiment where 50% of the subjects get sick, what do you think your chances of getting sick would be?

Almost certainly would ____	Probably would ____	Almost Probably would not ____	Certainly would not ______

12. Would you volunteer for an experiment where you knew that: (Please answer all three)
    a) 50% of the subjects did get motion sick? Yes ___ No ____

b) 75% of the subjects did get motion sick? Yes ___ No ____

c) 85% of the subjects did get motion sick? Yes ___ No ____

13. Most people experience slight dizziness (not a result of motion) three to five times a year. The past year you have been dizzy:
More than this ___ The same as ___ Less than ___ Never dizzy ___

14. Have you ever had an ear illness or injury which was accompanied by dizziness and/or nausea? Yes ___ No ____

15. Listed below are a number of situations in which some people have reported motion sickness symptoms. In the space provided, check (a) your PREFERENCE for each activity (that is, how much you like to engage in that activity), and (b) any SYMPTOM(s) you may have experienced at any time, past or present.

SITUATIONS	PREFERENCE			SYMPTOMS												
	LIKE	NEUTRAL	DISLIKE	VOMITED	NAUSEA	STOMACH AWARENESS*	INCREASED SALIVATION	DIZZINESS	DROWSINESS	SWEATING	PALLOR	VERTIGO**	AWARENESS OF BREATHING	HEADACHE	OTHER SYMPTOMS	NONE
Aircraft																
Flight simulator																
Roller Coaster																
Merry-Go-Round																
Other carnival devices																
Automobiles																
Long train or bus trips																
Swings																
Hammocks																

Gymnastic Apparatus																
Roller / Ice Skating																
Elevators																
Cinerama or Wide-Screen Movies																
Motorcycles																

*Stomach awareness refers to a feeling of discomfort that is preliminary to nausea.
**Vertigo is experienced as loss of orientation with respect to vertical upright.

B. PITTSBURGH SLEEP QUALITY INDEX

INSTRUCTIONS: The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month. Please answer all questions.
During the past month,
1. When have you usually gone to bed?
2. How long (in minutes) has it taken you to fall asleep each night?
3. When have you usually gotten up in the morning?
4. How many hours of actual sleep do you get at night? (This may be different than the number of hours you spend in bed)

5. During the past month, how often have you had trouble sleeping because you	Not during the past month (0)	Less than once a week (1)	Once or twice a week (2)	Three or more times a week (3)
a. Cannot get to sleep within 30 minutes				
b. Wake up in the middle of the night or early morning				
c. Have to get up to use the bathroom				
d. Cannot breathe comfortably				
e. Cough or snore loudly				
f. Feel too cold				
g. Feel too hot				
h. Have bad dreams				
i. Have pain				
j. Other reason(s), please describe, including how often you have had trouble sleeping because of this reason(s):				
6. During the past month, how often have you taken medicine (prescribed or "over the counter") to help you sleep?				
7. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?				
8. During the past month, how much of a problem has it been for you to keep up enthusiasm to get things done?				
	Very good (0)	Fairly good (1)	Fairly bad (2)	Very bad (3)
9. During the past month, how would you rate your sleep quality overall?				

C. EPWORTH SLEEPINESS SCALE

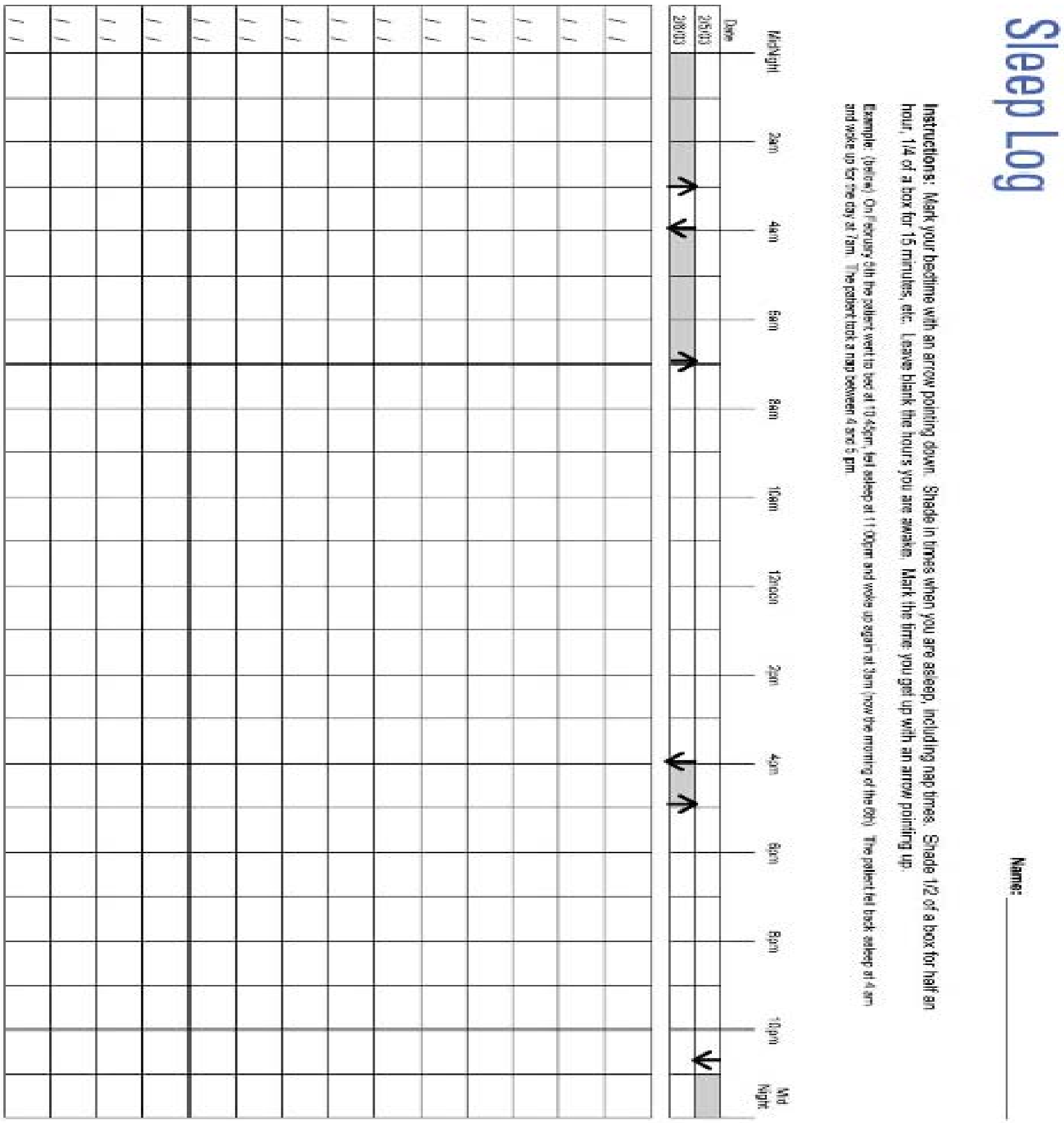
In contrast to just feeling tired, how likely are you to doze off or fall asleep in the following situations? (Even if you have not done some of these things recently, try to imagine how they would have affected you.) Use the following scale to choose the most appropriate number for each situation:

0 = Would never doze
1 = Slight chance of dozing
2 = Moderate chance of dozing
3 = High chance of dozing

Situation	Chance of Dozing
Sitting & Reading	____________
Watching TV	____________
Sitting inactive in a public place (i.e. theatre)	____________
As a car passenger for an hour without a break	____________
Lying down to rest in the afternoon	____________
Sitting & talking to someone	____________
Sitting quietly after lunch without alcohol	____________
In a car, while stopping for a few minutes in traffic	____________
TOTAL SCORE	____________

APPENDIX C. DAILY SLEEP LOG

The following is the weekly sleep log that each participant was required to complete during the baseline data collection period.



Sleep Log

Name: ____________

Instructions: Mark your bedtime with an arrow pointing down. Shade in times when you are asleep, including nap times. Shade 1/2 of a box for half an hour, 1/4 of a box for 15 minutes, etc. Leave blank the hours you are awake. Mark the time you get up with an arrow pointing up.

Example: (below) On February 5th the patient went to bed at 10:45pm, fell asleep at 11:00pm and woke up again at 3am (now the morning of the 6th). The patient fell back asleep at 4 am and woke up for the day at 7am. The patient took a nap between 4 and 5 pm.

Date	MidNight	2am	4am	6am	8am	10am	12noon	2pm	4pm	6pm	8pm	10pm	Mid Night
2/5/03													
2/6/03													
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APPENDIX D. POST-EXPERIMENT SURVEY

The following is the post-experiment survey that the researchers administered to the participants.

Post-Experiment Survey

Please answer the following questions regarding the sleep you obtained during your two nights in our laboratory. Please circle only one answer per question.

Answer the next six questions only if you slept on the standard Navy mattress.

1. Compared to how you normally sleep at home, please rate how you slept on the standard Navy mattress in a zero-motion condition.

Much Worse	Worse	About the Same	Better	Much Better
1	2	3	4	5

2. Compared to how you normally sleep at home, please rate how you slept on the standard Navy mattress in the motion condition.

Much Worse	Worse	About the Same	Better	Much Better
1	2	3	4	5

3. Compared to how you slept on the standard Navy mattress in a zero-motion condition, please rate how you slept on the standard Navy mattress in the motion condition.

Much Worse	Worse	About the Same	Better	Much Better
1	2	3	4	5

4. Please describe the amount of shock and vibration you felt while sleeping on the motion platform.

A Tremendous Amount	A Great Deal	A Moderate Amount	A Small Amount	None
1	2	3	4	5

5. Please rate how well rested you felt after sleeping on the standard Navy mattress in a zero-motion condition.

Extremely Well	Very Well	Moderately Well	Well Rested	Not Well Rested
1	2	3	4	5

6. Please rare how well rested you felt after sleeping on the standard Navy mattress in the motion condition.

Extremely Well	Very Well	Moderately Well	Well Rested	Not Well Rested
1	2	3	4	5

Answer the next six questions only if you slept on the Tempur-Pedic mattress.

7. Compared to how you normally sleep at home, please rate how you slept on the Tempur-Pedic mattress in a zero-motion condition.

Much Worse	Worse	About the Same	Better	Much Better
1	2	3	4	5

8. Compared to how you normally sleep at home, please rate how you slept on the Tempur-Pedic mattress in the motion condition.

Much Worse	Worse	About the Same	Better	Much Better
1	2	3	4	5

9. Compared to how you slept on the Tempur-Pedic mattress in a zero-motion condition, please rate how you slept on the Tempur-Pedic mattress in the motion condition.

Much Worse	Worse	About the Same	Better	Much Better
1	2	3	4	5

10. Please describe the amount of shock and vibration you felt while sleeping on the motion platform.

A Tremendous Amount	A Great Deal	A Moderate Amount	A Small Amount	None
1	2	3	4	5

11. Please rate how well rested you felt after sleeping on the Tempur-Pedic mattress in a zero motion condition.

Extremely Well	Very Well	Moderately Well	Well Rested	Not Well Rested
1	2	3	4	5

12. Please rate how well rested you felt after sleeping on the Tempur-Pedic mattress in the motion condition

Extremely Well	Very Well	Moderately Well	Well Rested	Not Well Rested
1	2	3	4	5

APPENDIX E. POST-EXPERIMENT SURVEY RESULTS

The following are all survey results that were deemed not significant.

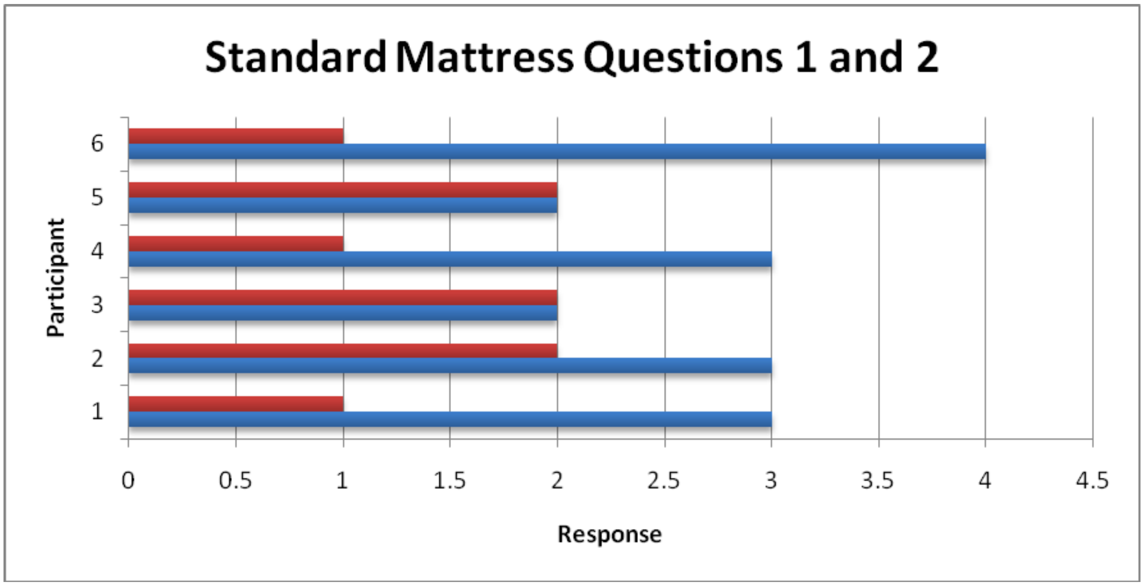

Figure E1. Questions 1 and 2 Responses (Standard Mattress)

Test Statistic	-5
Prob < z	0.06

Table E1. Wilcoxon Rank Sum Test

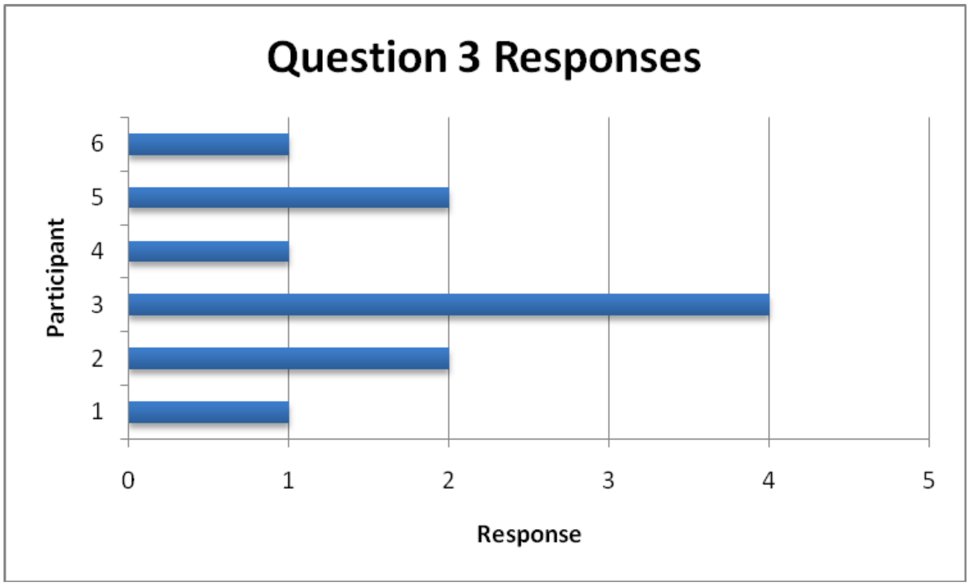

Figure E2. Question 3 Responses (Standard Mattress)

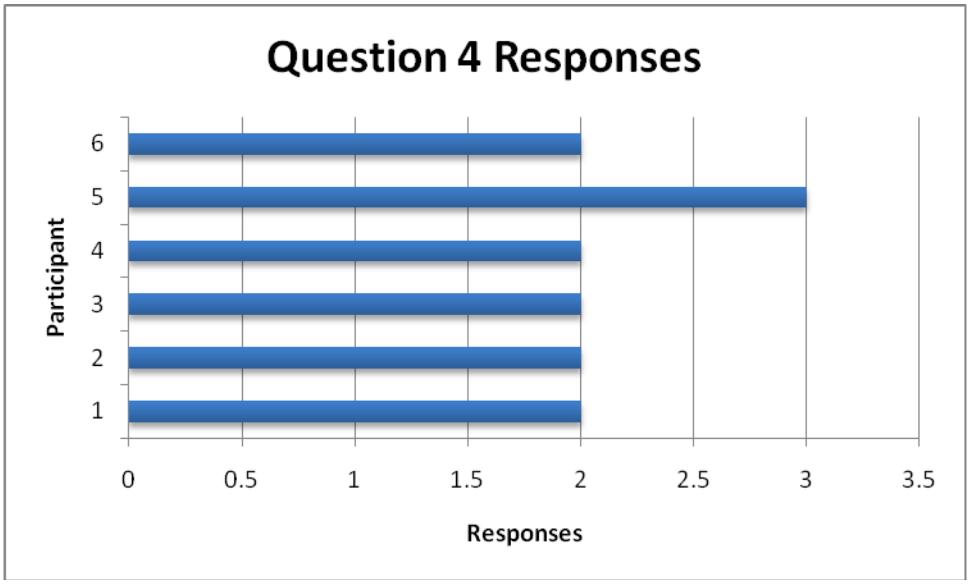

Figure E3. Question 4 Responses (Standard Mattress)

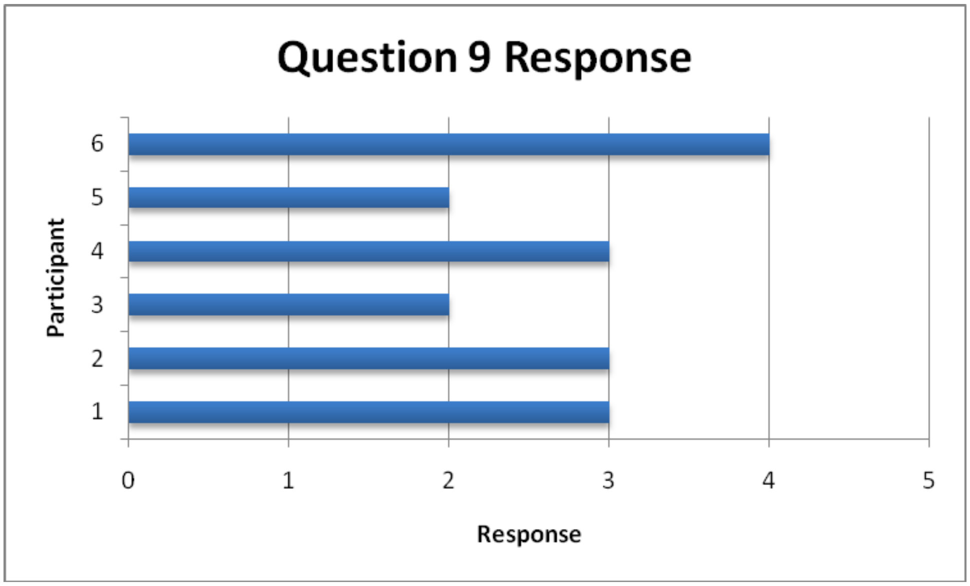

Figure E4. Question 9 Responses (V/E)

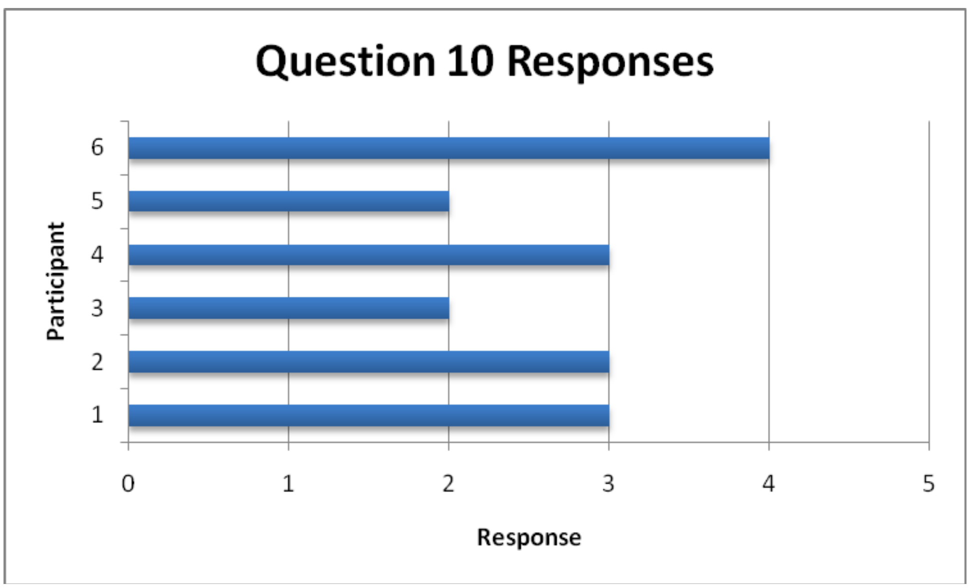

Figure E5. Question 10 Responses

Mattress Type	Participants	Score Sum	Score Mean	(Mean-Mean0)/Std0
ST	6	34	5.7	-0.9
VE	6	44	7.3	0.9

Table E2. Questions 1 and 7 Summary Statistics

S	Z	*p* Value
44	0.8	0.4

Table E3. Questions 1 and 7 Wilcox Rank Sum

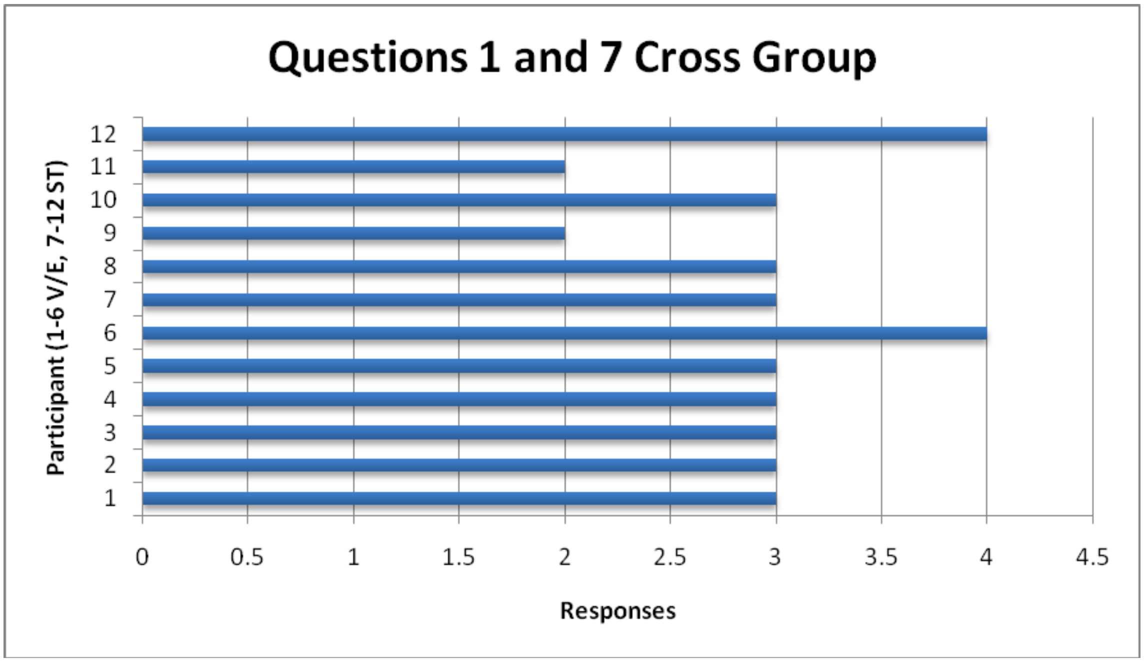

Figure E6. Questions 1 and 7 Responses (Cross Group)

Mattress Type	Participants	Score Sum	Score Mean	(Mean-Mean0)/Std0
ST	6	39	6.5	0
VE	6	39	6.5	0

Table E4. Questions 2 and 8 Summary Statistics

S	Z	*p*Value
39	0	1

Table E5. Questions 2 and 8 Wilcoxon Rank Sum Test

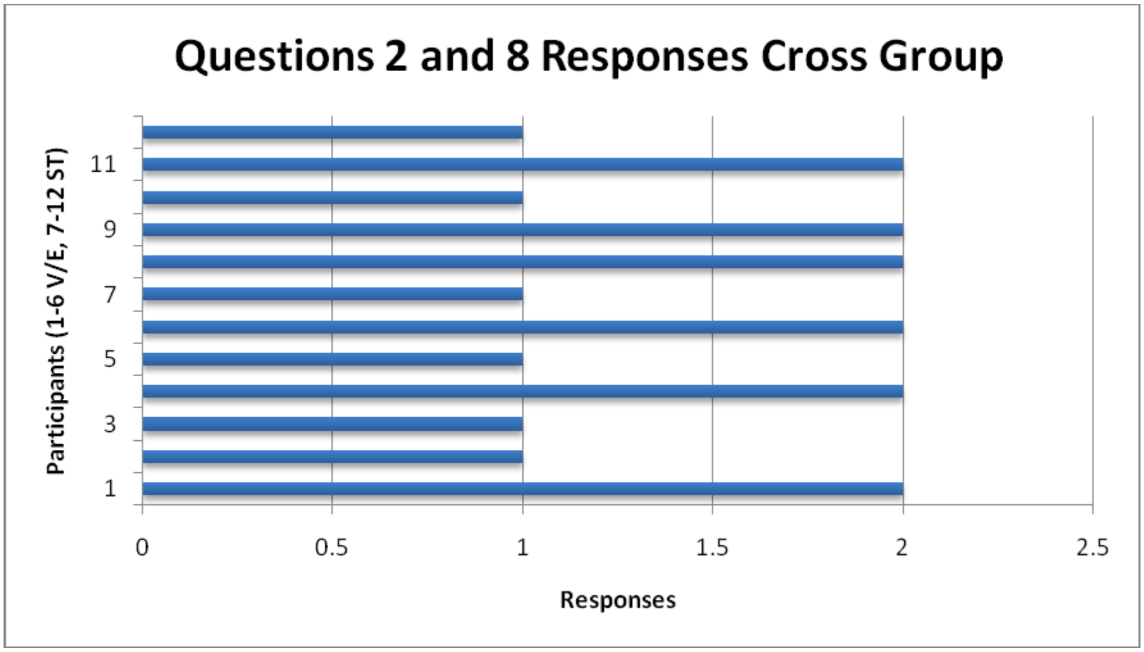

Figure E7. Question 2 and 8 Responses (Cross Group)

Mattress Type	Participants	Score Sum	Score Mean	(Mean-Mean0)/Std0
ST	6	41	6.8	0.3
VE	6	37	6.7	-0.3

Table E6. Questions 3 and 9 Summary Statistics

S	Z	*p*Value
37	0.3	0.8

Table E7. Questions 3 and 9 Wilcox Rank Sum

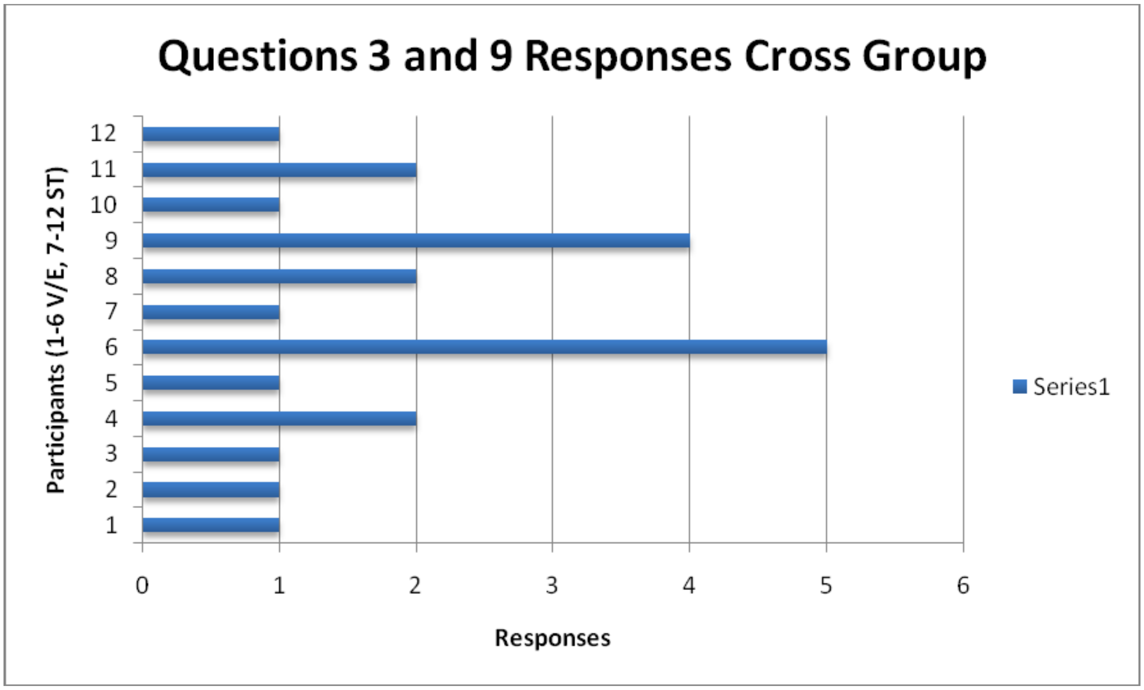

Figure E8. Questions 3 and 9 Responses (Cross Group)

Mattress Type	Participants	Score Sum	Score Mean	(Mean-Mean0)/Std0
ST	6	43.5	7.25	0.7
VE	6	34.5	5.75	-0.7

Table E8. Questions 5 and 11 Summary Statistics

S	Z	*p* Value
34.5	0.7	0.5

Table E9. Questions 5 and 11 Wilcoxon Rank Sum Test

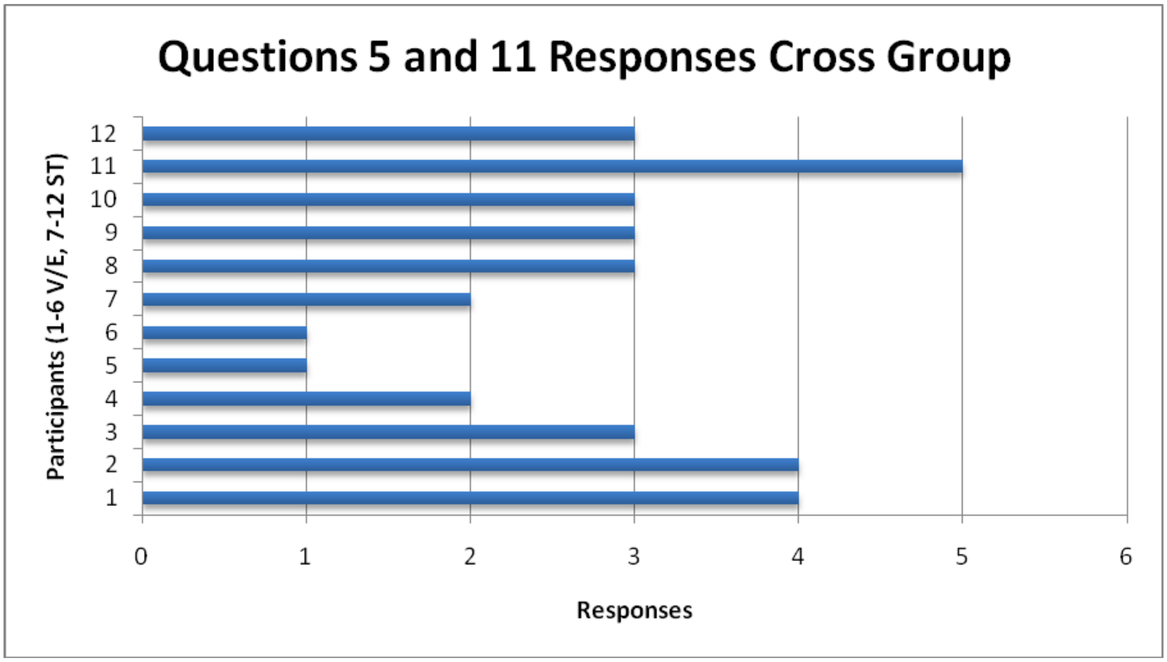

Figure E9. Questions 5 and 11 Responses (Cross Group)

Mattress Type	Participants	Score Sum	Score Mean	(Mean-Mean0)/Std0
ST	6	46	7.7	1.2
VE	6	32	5.3	-1.2

Table E10. Questions 6 and 12 Summary Statistics

S	Z	*p* Value
32	1.2	0.2

Table E11. Questions 6 and 12 Wilcoxon Rank Sum Test

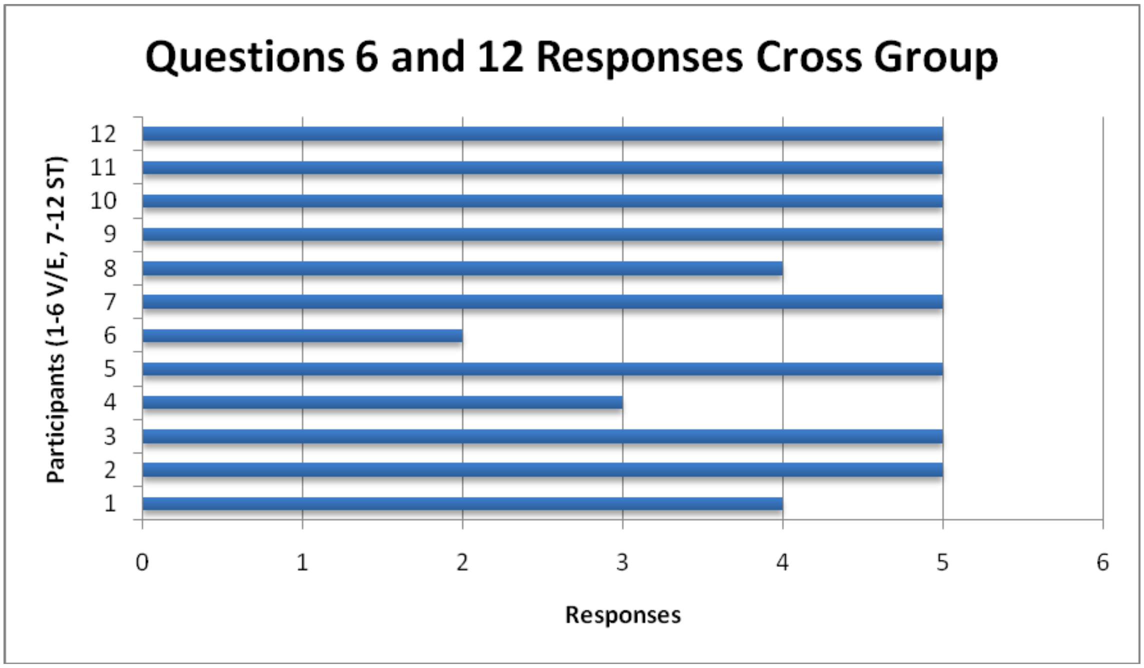

Figure E10. Questions 6 and 12 Responses (Cross Group)

Mattress Type	Participants	Score Sum	Score Mean	(Mean-Mean0)/Std0
ST	6	29.5	4.9	-1.6
VE	6	48.5	8.1	1.6

Table E12. Questions 4 and 10 Summary Statistics

S	Z	*p* Value
48.5	1.64316767	0.1

Table E13. Questions 4 and 10 Wilcoxon Rank Sum Test

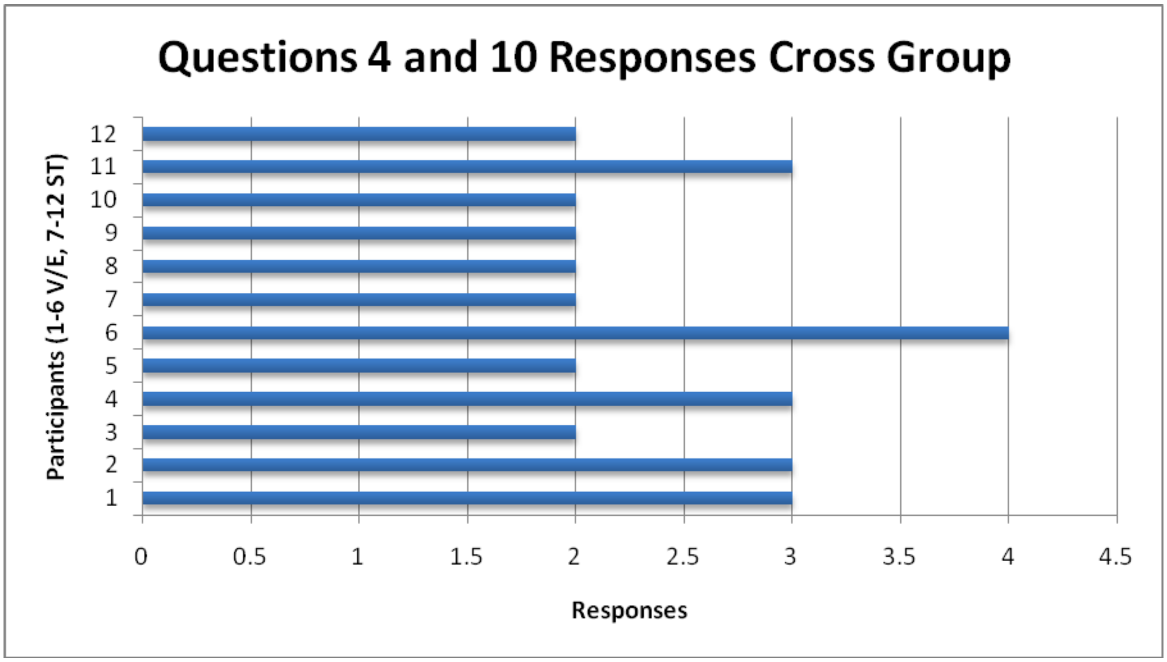

Figure E11. Questions 4 and 10 Responses (Cross Group)

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APPENDIX F. CALL FOR PARTICIPANTS

Volunteer to Sleep!!!
Call for Participants

NPS Students,

For our thesis, LT Matt Sullivan and LTJG Brian Grow would like to ask you to be participants in a study looking at the **effects of motion on sleep**.

The project will also assess whether sleeping surface has an effect on sleep quality. We will be using a **standard Navy rack mattress and a Tempur-Pedic mattress**. The study will require participants to wear a "sleep watch", a wrist-worn activity monitor, for one week prior to the experiment, while keeping a log of basic work/rest related activities. Then, each participant will be asked to spend two nights sleeping here at NPS. You will be randomly assigned to either a standard Navy mattress, or a visco-elastic mattress. After that, you will spend one night on your mattress in a zero-motion condition, and one night on our shipboard motion simulator.

This study may enable the Navy to consider new sleeping surfaces, while reevaluating watch schedules and crew sizes on the ships of the future.

If you are interested in participating in this important study, please contact either LT Matt Sullivan or LTJG Brian Grow at msulliva@nps.edu or bjgrow@nps.edu. Please set up a time to meet with us to complete a brief survey to determine whether you qualify for the study. **Personnel with shipboard experience are preferred.**

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